UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
OREGON STATE OFFICE

Minor revision in road standards, tests for surfacing rock, and other areas such as road terminology have been implemented in Bureau road programs since publication of this handbook. These changes are minor and do not effect the utilization of the handbook as A Guidebook for Logging Planning and Forest Road Engineering.

FOREST ENGINEERING HANDBOOK

1961

PREFACE

This Handbook was prepared by J. Kenneth Pearce, Professor of Logging Engineering, University of Washington, while employed by the Oregon State Office of the Bureau of Land Management. It has been compiled to fill a need that is not, in its entirety, covered by any existing forestry or civil engineering literature. The technical problems confronting the forest engineer are numerous and each problem requires careful judgment in the application of sound logging and road engineering principles correlated with the objectives of multiple use forest management. This Handbook is for forest engineers and foresters engaged in the preparation of logging plans and all phases of road engineering from reconnaissance through construction engineering. It is designed to be used as a reference handbook as well as a text for training and operation purposes.

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FOREST ENGINEERING HANDBOOK

A Guide For
Logging Planning
Forest Road Engineering

DIVISIONS

CONTENTS

100 CONSIDERATIONS IN LOGGING PLANNING

100.1 INTRODUCTION. Logging planning means determining how the timber on a given tract shall be removed. The logging plan is the "blueprint" for the logging operation. The plan embraces the logging methods, the location of landings and setting boundaries, the sequence of cutting and the entire forest road system for the tract. From felling site to log truck dump, logging is transportation. Moving the logs to the landing historically is termed minor transportation. Loading on trucks and hauling over the road system is major transportation. Even access roads, although constructed independently of timber sales, are a part of the logging plan. The primary purpose of the access road is to serve the logging. Administrative, protective and recreational uses, although important, are secondary to log hauling.

The logging planner is the "architect" of the logging plan. To arrive at the best plan, he must consider many factors. Given the basic data on timber and topography, logging planning requires the concurrent consideration of the following factors:

1. The physical requirements of the applicable logging methods.

2. The most economical combination of yarding costs, road construction costs and trucking costs.

3. The silvicultural system and the priority sequence of cutting.

4. Protection of the uncut stand and soil and water resources.

5. The safety of the men working on the landings and traveling the roads.

Some of these factors may conflict. The final logging plan may be a compromise reached after weighing all factors. The relative weight to be given each factor is an administrative decision based on policy.

The logging planning divisions of the Forest Engineering Handbook are prepared to serve two purposes. The first is to fill some of the gaps in the education of the junior forester. The forest management curriculum of most forestry schools is deficient in instruction in logging planning. The second purpose is to serve as a reminder to the more experienced planner of considerations which, in his pre-occupation with the more pressing ones, may be overlooked.

110 PHYSICAL REQUIREMENTS OF YARDING METHODS

111 HIGH LEAD

111.1 CONDITIONS TO WHICH ADAPTED. The high-lead system is best adapted to yarding clear-cut settings. However, with the exercise of care by the yarding crew, the high-lead can also be used for pre-logging the smaller understory trees to save breakage, or for yarding tree selection or partial cuttings.

The high-lead operates most efficiently yarding up the slope. When the mainline lead block is above the elevation of the turn of logs, a vertical component of force exerted on the mainline is available to lift the turn over obstacles (see Fig. 111-1). The yarding trails fanning out from the landing disperses the runoff and reduces erosion (see Fig. 111-2). Slash is also scattered.

When high-lead yarding down the slope, there is no lift on the turn, above the elevation of the block, to free it from "hang-ups". Yarding trails converge at the landing with consequent concentration of runoff and slash. There is a hazard to the men on the landing from sliding logs or chunks. However, on very steep slopes where the bulk of the timber volume felled will come to rest on the lower part of the slope, yarding down-slope is indicated. Where a full circle around a spar tree is yarded, as is common practice on side slopes, it is preferable to have the longer yarding distance on the lower side and the shorter distance on the upper side.

111.2 YARDING DISTANCE. Economic high-lead yarding distance is determined by the following physical factors:

1. The height of the spar tree. The taller the spar, the greater the effective lift on the turn. Spar trees are usually "topped" at the point where the diameter is about 24 inches. Douglas-fir is the only species suitable for a spar tree.

2. The size of the yarder. Yarder horse power, line speed and drum capacity.

3. The topography. An unobstructed line of sight between any point on the setting and the mainline block is essential for efficient operation. The high-lead cannot yard turns effectively from behind ridges or out of draws where the mainline bends in a vertical plane.

4. The volume per acre to be logged. Light stands generally call for a longer yarding distance than heavy stands in order to keep the combined "fixed per acre" costs of moving, rigging and road changing and the "yarding varible" costs at a minimum

FIG. III-1 HIGH LEAD PROFILE

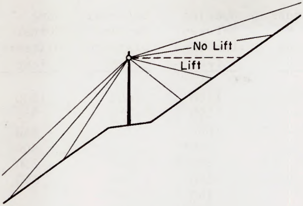


FIG. III-2 YARDING ROADS

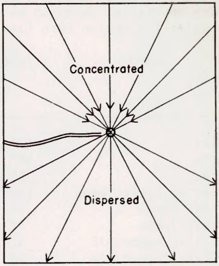
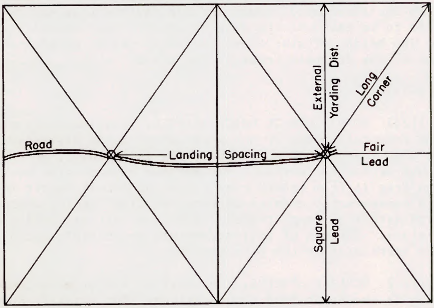


FIG. III-3 SETTING NOMENCLATURE



111.3 YARDING DISTANCE TABLE. The following high-lead yarding distance table, representing the concensus of a number of efficient logging operators, is given as a general guide for average stands in the Douglas-fir region (see Fig. 111-3):

Spar	Heights	Yarder H. P. Range	Spacing Between Landings feet	External Yarding Distance feet	Long Corner Distance feet
Tree	175	250-300	1200	800	1000
Tree	150	200-250	1100	750	950
Tree	125	175-200	1000	700	850
Tree or Steel Tower	100	130-175	1000*	600	800
Steel Tower	90	130-200	900**	600	750
Steel Tower	50	40-80	800	500	650
Mobile Logger SJ8	42	157	300	500	
Mobile Logger SJ4	30	170	200	400	

* Since less time and cost are required to move and rig up a steel tower, the landing spacing is often shorter.
**One operator spaces landings at 500 feet intervals and yards only two quarters to each landing.

In logging planning for sales of Bureau of Land Management timber where the successful bidder and his equipment is not yet known, the planning has to be based on the size of yarders most commonly used in the locality. The height of spar trees available can be determined from measurement of the dominant trees in the stand.

112 SKYLINES

112.1 CONDITIONS TO WHICH ADAPTED. Skyline systems are adapted to swinging from cold decks or hot decks where swing distances are too long for a high lead swing, where the swing is downhill, or the swing road is over rough or broken terrain. The skyline systems give more lift to the turn to free it from ground conditions and permit faster hauling speeds with consequently greater output. Skyline yarding systems are used to a limited extent in rough terrain where most of the yarding must be done down slope. The use of skyline systems on erosible soils instead of tractors is increasing in the pine region.

112.2 SKYLINE SYSTEMS. The skyline system most commonly used for swinging is the North Bend tight-skyline. For swinging down steep slopes the modified North Bend with a two-part mainline between fall block and carriage gives more lift and better control of the turn. In the ponderosa pine region on erosible soils where tractor skidding is not permitted, the Swiss Wyssen system, the Berger interlocking skidder, and the Skagit slackline are being tested. The Skagit "radio-controlled sky carriage" is being tested in the Douglas-fir region. This is a gravity system as is the Wyssen. For diagrams of cable rigging systems. (1/)

112.3 SWINGING DISTANCE. Swinging distance is usually twice high-lead yarding distance or 1200 to 1600 feet. Distance is limited by deflection obtainable and the length of skyline available. Skyline yarding distance ranges from 1000 to 1500 feet for slackline and skidder, to 5000 feet for the radio controlled sky carriage and the Wyssen system.

The Grabinski high-lead, sometimes called the "scab skyline", is a modification of the high-lead which enables a lift to be given to the turn to free it from hangups. The butt rigging is attached to a traveling block which is hung on the haulback line. The haulback runs directly from spar tree back to tail block and forward to the butt rigging. This system is useful yarding down steep slopes or across short draws.

112.4 DEFLECTION. The most important factor in planning a skyline location is to obtain adequate deflection or sag at the center of the span so the desired turn can be carried with an adequate factor of safety. See section 231 for methods of measuring deflection and computing tension in skylines.

113 CRAWLER TRACTOR

113.1 CONDITIONS TO WHICH ADAPTED. The crawler tractor with logging arch is adapted to logging selection or partial cut settings. In the Douglas-fir region the tractor-arch is adapted to yarding clear cut settings downhill on slopes under 35 to 40 per cent, on soils which do not present an erosion hazard. Since tractor yarding is usually cheaper than high-lead yarding, logging operators prefer to use tractors where topography permits. A combination sometimes used on sidehill settings is to high-lead the lower side uphill and tractor yard the upper side downhill to the same landing. This increases loader output and reduces the combined yarding and loading cost. In the ponderosa pine region, where the tractor is usually the only skidding equipment available, slopes up to 60 per cent or more are tractor logged. However, tractor logging on steep slopes is not a safe practice.

113.2 CRAWLER TRACTOR ROADS. In the Douglas-fir region tractor roads are bulldozed preferably prior to felling the timber. The maximum favorable gradient on tractor roads should be limited to 25 to 30 per cent. The optimum gradient which will result in the fastest round trip time is 15 to 18 per cent. Uphill hauls slow down production and adverse grades on tractor roads are usually limited to 5 or 6 per cent. Recommended practice in locating a tractor road is to follow smooth curves. For safety avoid sharp bends or kinks which cause the rear end of turn of logs to swing wide. Tractor road spacing usually averages 150 to 175 feet.

113.3 YARDING DISTANCE. In the Douglas-fir region the usual external tractor yarding distance is 1200 to 1300 feet with long corners of 1500 to 1700 feet. In the pine region where volumes per acre logged are less, skidding distances are longer. However, the skidding distance should be determined by the optimum road spacing formula based on skidding cost, road construction cost and volume per acre (see Ch. 240). Recommended tractor logging references are (2/)and(3/).

114 WHEEL TRACTOR

114.1 CONDITIONS TO WHICH ADAPTED. The larger rubber-tired wheel tractor, with logging arch built in or attached, is basically a "roading" or swinging machine. Logs are bunched for the wheel tractor by crawler tractor or hot decked by high-lead. The high gear speed of the wheel tractor is two to three times that of a crawler tractor. Wheel tractors are especially well adapted to hauls too long for crawler tractors and too short to be economical for motor trucks because loading and unloading time would be disproportionate to the hauling time. The possibility of increasing truck road spacing and reducing the amount of road construction indicates increased use of wheel tractors in the future, particularly in the pine region. As a swing system in the Douglas-fir region, the wheel tractor is not limited by distance or deflection as is the skyline. However, the wheel tractor is best adapted to hauling logs down favorable grades.

114.2 WHEEL TRACTOR ROADS. To realize the advantages of the fast travel time of which wheel tractors are capable, wheel tractor roads should be engineered as carefully as spur truck roads. Studies of wheel tractor operations indicate the optimum gradient range to be between 20 and 30 per cent for favorable grades with a maximum of 40 per cent. Adverse grades should be avoided if possible. If unavoidable, adverse grades should be limited to short pitches and a maximum of 15 per cent. For steering control at maximum speed, curves should be limited to a minimum radius of 50 feet or 115 degrees. Experienced operators state that they prefer roads as straight as possible with more consideration given to alignment than to gradient.

115 PRE-LOGGING AND SALVAGE LOGGING

115.1 METHODS USED. Where topographic and soil conditions permit, crawler tractors are used for pre-logging to remove the smaller understory trees to save breakage when the large overstory trees are felled and yarded and to salvage wind thrown or dead trees from leave settings or seed blocks. Where conditions necessitate moving cable methods, mobile steel spars or mobile combination yarding and loading machines are commonly used. Maximum external yarding distance for these machines is about 500 feet. Where the road spacing for the main logging does not permit coverage of the entire area by the pre-logging or salvage machines, intermediate temporary summer earth roads can be built midway between the regular turck roads. If short-log trucks are used, trees can be dodged to avoid felling and stump blasting and intermediate temporary roads built quite inexpensively. (4/)

116 LOGGING METHODS FOR THINNINGS

116.1 HORSE SKIDDING. Horses are well adapted to skidding small logs such as thinnings in second-growth Douglas-fir. They can work on narrow skid trails and with little damage to the residual stand. Capital investment in horse and equipment is low. Advantages of horse skiddings are low capital investment, narrow skid trails, and minimum damage to the residual stand. Disadvantages are care and feeding when not working and the difficulty of finding good teamsters.

Horses are best suited for skidding down the slope on gradients under 40 percent. Maximum skidding distance should not exceed 500 to 600 feet. Skidding up the slope should be avoided. If unavoidable, adverse skidding should be limited to 10 percent gradient and 300 feet skidding distance. (5/)

116.2 TRACTOR SKIDDING. The same requirements given in sections 113 and 114 apply to the small crawler tractors and rubber-tired wheel tractors used in yarding thinnings. External yarding distances are usually 600 to 900 feet. However, skidding distance should be determined by optimum road spacing formula. Tractors are better adapted to adverse hauls since they do not tire as horses do. Man-hour production is greater with the tractor. Tractor roads should be kept as straight as possible to avoid damage to residual trees by scraping them with the tractor or with the turn of logs when going around sharp curves. Rubber-tired tractors are less damaging than crawler tractors.

117 LANDINGS

117.1 LANDING REQUIREMENTS. The landings to which logs are yarded for loading are of the greatest importance to the efficiency and safety of the operation. The side slope of the landing must be such that logs will not roll or slide when unhooked. They should be large enough that yarding output will not be restricted and logs will not have to be piled high, which would endanger men working on the landing. They should be well drained so mud does not accumulate and debris can be pushed away. Consequently, landings should be located on benches or ridges, not in draws. The yarding and leading method affect landing requirements. The larger shovel loaders require swing room of 60 feet between the center pin and the cut bank. Tree-rig booms may require more swing room.

117.2 HIGH-LEAD LANDINGS. The maximum side slope on a high-lead landing should not exceed 20 percent. The preferable landing circle radius is one and one-half the log length plus the road width. Where the landing must be excavated on a steep slope, the minimum radius is the longest log length. Good guyline stumps must be available in a circle around the landing. If a satisfactory spar tree is not growing on the landing, a tree suitable for a "dummy" for raising a spar tree is required. On steep slopes a stump above the landing can be used instead of a dummy tree. Space for the yarder, clear of trucks and loader, with good visibility for the yarder operator is required.

117.3 TRACTOR LANDINGS. The side slope on tractor landings should not exceed 10 to 15 percent. The landing should be rectangular in shape and not less than 80 feet long and 40 feet wide on the side approached by the tractor roads. Efficiency in tractor logging is obtained only when the landing is wide enough that no tractor has to wait upon another to unhook the turn. The entering tractor road should be below the elevation of the unhook site so mud and water will drain off.

117.4 ROAD GRADIENT AT LANDING. The gradient of the truck road at the landing should not exceed 5 percent. A gradient at 3 percent is preferable for truck maneuverability. The minimum gradient is 1 percent for drainage.

120 ECONOMIC CONSIDERATIONS

121 LOGGING COSTS

121.1 PLANNING DETERMINES COSTS. The primary objective of logging planning is to obtain the lowest logging cost consistent with other forest management objectives. Yarding and loading cost, spur road construction cost and the off-highway portion of the trucking cost are directly affected by the logging plan. These items generally comprise 40 to 50 percent of the total logging cost. The importance of economic considerations is evident when the work of the logging planner is reflected in activities which comprise half the logging cost.

The most economical logging plan is that for which the combined yarding and loading costs and spur road costs per M board feet are a minimum. To achieve the most economical plan requires a knowledge of costs and the variable factors influencing cost elements. Road patterns and road spacing are also important economic considerations. The costs given in Section H, Chapter III of the <u>Timber Sale Procedure Handbook</u> for stumpage appraisal are useful aids in planning. A file of output and cost data on local operations would be a helpful supplement. The logging planner should not neglect any opportunity to add to his file of local cost data.

121.2 COST CLASSIFICATIONS. Following are the standard classifications used in logging cost analysis. All costs are unit costs, i.e., cost in dollars and cents per unit of measurement, such as M board feet or cords.

"Fixed per acre" costs are those which depend on the volume per acre and the acreage served. Examples are landing expense (moving and rig-up), high-lead road changing, and truck roads.

"Fixed per turn" costs are those chiefly influenced by the size of the logs and the number of logs in the turn.

"Yarding variable" costs are those chiefly influenced by yarding distance and log size. This is the cost of the actual hauling-in of the turn of logs. Haul-back time is usually included with haul-in time for "yarding variable" cost even though the haul-back is affected only by distance.

"Fixed per M" costs are chiefly influenced by production over a period of time. Examples are overhead costs such as administration. Contract work at a rate per M board feet is a "fixed per M" cost, although the rate will be affected by log size.

121.3 HIGH-LEAD YARDING COST FACTORS. High-lead yarding costs in the Douglas-fir region vary over a wide range of conditions of timber stand and topography. The following tabulation shows the factors influencing the various elements of yarding cost for a given yarder and crew.

Cost Classification	Activity	Factor Influencing	Cost per M Increased by
Fixed per acre	Landing Expense	Volume per acre Setting area	Lighter volume Smaller area
Fixed per acre	Road changing	Volume per acre Terrain	Lighter volume Steep, brushy, etc.
Fixed per turn	Choker setting (hook)	Turn size Log size Terrain	Smaller turns Smaller logs Steep, broken, brushy, swampy
Fixed per turn	Chasing (unhook)	Log size Turn size Landing Loading	Smaller logs Smaller turns Poor landing Waiting on loaders
(All of the above activities are influenced by labor efficiency.)			
Yarding variable	Mainline (haul-in)	Turn size Yarding distance Slope Topography	Smaller turns Longer distance Steeper slope Broken
Yarding variable	Haulback (haul-out)	Yarding distance	Longer distance

"Fixed" costs are also influenced by labor efficiency and "yarding variable" costs by yarder power and speed. In addition, as for all logging activities, the cost on net scale basis will depend on the difference between net or "water" scale and gross or "woods" scale due to defect and breakage. The most important factors influencing yarding costs are log and turn size, yarding distance and volume per acre. The influence of steepness of slope is more noticeable with large logs or under-powered yarders.

121.4 HIGH-LEAD YARDING COST FORMULA. For the purpose of comparing proposed settings, or the effect of changing boundaries of a setting, the following approximate formula for quickly estimating high-lead yarding cost is given. It is developed from the formula for estimating man-hours per M by Carow and Silen.(6/) It is based on a labor cost equal to 70 per cent of the total current operating cost. Ownership costs are not included.

$$\text{Yarding Cost per M} = L\left(1.07 + \frac{DS}{VB}\right)$$

Where L is the current labor cost in dollars per hour including social security, fringe benefits and industrial insurance; D is the average external yarding distance in feet; S is the side slope in percent; V is M board feet per acre; and B is the size of the average log in board feet. The above formula is applicable only when the physical requirements of the high-lead method are adhered to in selecting setting boundaries.

The "landing" cost per M (moving, rig-up and landing preparation) must be added to ascertain the effect of the size of the setting.

$$\text{Landing Cost per M} = \frac{\text{Landing Expense}}{\text{Setting Area X Volume per Acre}}$$

For more precise costs, see Section H, Chapter III, Timber Sale Procedure Handbook.

121.5 TRACTOR SKIDDING COST FACTORS. It is axiomatic that where conditions are suitable for tractors, tractor logging will be cheaper than high-lead logging. The factors influencing the various elements of tractor skidding cost per M for a given tractor are as follows:

Cost Classification	Activity	Factor Influencing	Cost per M Increased by
Fixed per acre	Bulldozing "cat" roads	Volume per acre Slope	Lighter volume Steeper slope
Fixed per turn	Hook	Log size Turn size Volume per acre	Smaller logs Smaller turn Lighter volume
Fixed per turn	Unhook	Log size Turn size Landing	Smaller logs Smaller turn Poor landing (delays)
Variable skidding	Haul-in	Turn size Skidding distance Grade	Smaller turn Longer distance Adverse grade
Variable skidding	Haul-out	Distance Grade	Longer distance Steeper grade

(Costs are also influenced by labor efficiency and organization of the work to avoid losses in output due to delays.)

121.6 COMBINED YARDING METHODS. Where a steep slope adjoins a gentle slope, combined tractor and high-lead yarding to one landing will give a lower cost than the high-lead alone. The roads and landings are located along the lower edge of the gentle slope. The steep slope is high-lead yarded up and the gentle slope tractor yarded down. This combination of methods results in higher output by the loader and reduces loading cost.

The economic yarding distance of a high-lead may be extended and the output increased by "feeding" the high-lead with a tractor on suitable ground. The cost of the combined methods will be in proportion to the volume handled by each method and the respective yarding costs.

121.7 DECKING AND SWINGING COST FACTORS. Decking and swinging is economically justified only when the total cost per M of decking, swinging and loading is less than the combined cost per M of direct yarding and loading plus the cost of spur road construction to the landing at the deck site. When the deck site is inaccessible by road because of difference in elevation or other topographic obstacles, decking and swinging is the only alternative to leaving the setting. Increased use of rubber-tired tractors for swinging or roading in the future is anticipated. Following are the possible decking and swinging combinations: high-lead cold deck and skyline swing; high-lead hot deck and tractor roading; tractor hot deck and wheel tractor roading; tractor hot deck and skyline swing. The high-lead may be used for short swings on favorable swing road profiles. Swings from hot decks are dependent on yarding output. Swings from cold decks are independent of yarding, so production will be greater.

The fixed per turn costs of hooking and unhooking on skyline swings average about 85 per cent of high-lead fixed per turn costs. Swinging variable costs per station of skyline span average about one-third of high-lead yarding variable costs. The cost of rigging-up a North Bend skyline is added to the swing landing expense. The expense of moving a tractor mounted triple drum, the machine commonly used for cold decking, plus the cost of bulldozing a tractor road to the cold deck site, is added to the cost of rigging a cold deck spar tree.

In the absence of local cost data on tractor roading, it is suggested that 80 per cent of tractor skidding fixed per turn cost of hooking and unhooking be used for cost comparison purposes. Since tractor yarding is done on bulldozed roads, yarding variable cost may be used for tractor swinging variable cost. Variable roading cost per station will depend upon tractor travel time as determined by swing road gradient and alignment. This may be calculated by reference to handbooks published by tractor manufacturers. (3/) Otherwise, use available variable skidding cost per station for estimating comparative costs. The fixed per acre cost per M of bulldozing the tractor road will depend upon the amount of clearing and earth moving required and the volume on the hot deck setting.

121.8 LOADING COST FACTORS. The most important factor influencing loading cost per M board feet is log size. Since loading is a "dependent" activity, dependent on yarding, loading cost is also influenced by yarding output. Considerations in logging planning which affect loading cost are: yarder output as controlled by yarding distance; choice of landings to provide adequate log storage and boom swing room; landing side slope which will permit the loading crew to work efficiently and safely; and road gradient on which the truck can maneuver readily and safely.

From the formula for loading man-hours per M board feet in reference (6/), the following approximate formula for loading cost is developed. It is based on a labor cost of 80 per cent of the total current operating cost.

$$\text{Loading Cost per M} = L\left(\frac{700}{B} - 0.47\right)$$

Where L is the current loading labor cost in dollars per hour and B is the average log size in board feet. The cost of loading from a skyline swing from a cold deck is less than the cost of loading on a yarder side due to the higher output.

121.9 LANDING COST FACTORS. The "landing" cost, also termed "rig-up" cost, is the sum of the costs per M board feet of the activities tabulated below together with the factors which influence them:

Activity	Factor Influencing
Bulldozing landing (clearing and earthmoving)	Side slope Size of landing
Moving yarder or tractors and loader	Distance to move Mobility of equipment
Rigging spar tree	Size of spar tree
Raising or "jumping" spar tree	Size of spar tree Distance to yard spar tree
Placing brow logs	Distance to move brow logs

(Felling for guyline clearance generally is charged to felling and bucking.)

The elements of landing expense over which the logging planner has control are the side slope and size of the landing (Section 118) and the spacing between landings which determines moving distance. Selecting a landing with a suitable spar tree has become unimportant with the prevalent practice of raising spar trees to put them in the best position on the landing for efficient yarding. However, it is necessary to have a suitable "dummy" tree at the landing, except on steep slopes where the spar tree can be raised from a lead to a stump above the landing. Where portable steel towers are used, no dummy is needed.

The landing expense divided by the volume of timber on the setting gives the landing cost in dollars per M. The logging planner exercises the greatest influence on landing cost in the size of the setting. For this reason, in cost estimating for logging planning, the landing cost is allocated to yarding.

121.10 ROAD AND TRUCKING COST FACTORS. The factors influencing road construction and maintenance costs and truck travel time and log trucking costs are given in detail in Division 300, "Considerations in Road Engineering". Road construction costs per M board feet vary widely with topography and volume of timber tapped by the road. Determination of economical road standard is given in Section 312. Planning the logging roads on lands for which the Bureau of Land Management is responsible is often complicated by existing roads on adjacent private land. Many of the O&C sections alternate with private sections in a checkerboard pattern. In some cases the private sections have been logged. The existing roads require careful study and evaluation to ascertain whether they fit into the most economical road pattern for the BLM lands. Allowing existing roads on adjoining land to unduly influence the logging planning for the BLM land may result in an inferior plan. Where an existing road is of a poor standard and inconsistent with the standard indicated for the BLM road from the standpoint of trucking cost and future maintenance, it is better to abandon the existing road. Where intermingled private lands have not yet been logged, every effort should be made to obtain cooperative planning of the road system for the entire drainage. All ownerships will benefit from such cooperation.

121.11 EVALUATING AN EXISTING ROAD. Following is a guide for evaluating an existing road to ascertain whether it is acceptable:

1. Standard of existing road for comparison with standard of proposed Bureau of Land Management road

    a. Width - surface and subgrade

    b. Gradient - maximum favorable and adverse

    c. Alignment - maximum degree of curve spacing

    d. Turnouts - on blind curves and turnout spacing

2. Condition of existing road

    a. Surfacing - depth sufficient (see Section 631); capable of being graded smooth

    b. Subgrade compacted - no further settlement anticipated

    c. Drainage - culverts and ditches adequate

    d. Bank slopes - angle of repose of soils reached

    e. Erosion - negligible

3. Volume of timber to be served by the road. If the volume is relatively small (under 2,500 M board feet) and the existing road is usable, it would be acceptable.

4. If the road is substandard, the feasibility of bringing it up to standard and the estimated cost.

An existing road may be considered to be "usable" if it does not exceed the following specifications:

1. Surface width 10 feet

2. Subgrade width 16 feet

3. Maximum degree of curve 95°

4. Turnout spacing 1000 feet

5. Drainage adequate to minimize danger of washouts

122 ROAD PATTERNS

122.1 ROAD PATTERNS. The road pattern which will give the least density of roads per section while maintaining optimum yarding distance is the ideal to be sought. Keeping the density of roads to an economical minimum has initial cost advantages and future advantages in road maintenance costs and the acreage of land taken out of forest production. The road system for logging one side of a main drainage will usually be one of the following patterns:

1. A systematic pattern of regularly spaced parallel roads. On long side slopes they may be:

    a. Contour roads paralleling the main creek connected by a single climbing road on maximum grade. The contour road may follow a "grade-contour" of low per cent favorable grade.

    b. Parallel climbing roads from a main road along the valley bottom. These roads usually switch-back from the main road but may take off in the same direction on steeper grades than the main road.

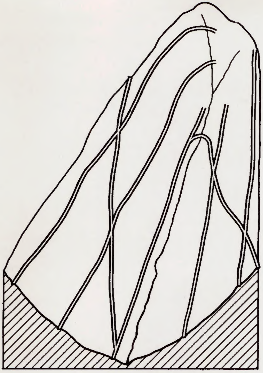
2. A systematic pattern of ridge and valley roads. This pattern is followed where side slopes are short and steep and the timber can be reached from two roads: one along the bottom of the valley and the other along the crest of the ridge. The connecting road is located where topography is the most favorable.

3. A random pattern of irregularly spaced roads. This pattern usually is the result of not planning far enough ahead to obtain a systematic pattern.

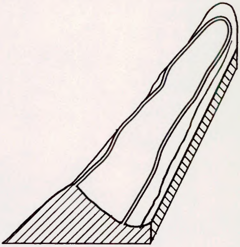
Road patterns are illustrated in Figure 122-1.

122.2 SYSTEMATIC CONTOUR ROAD PATTERN. The systematic parallel grade-contour road pattern is recommended where main drainage side slopes are long, requiring more than two levels of roads and are interspersed with benches or spur ridges suitable for landings. This is typical of the

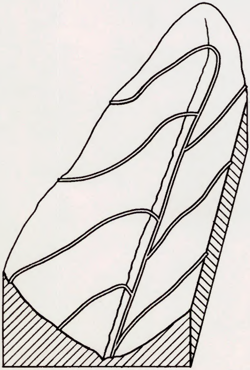
FIG. 122-1 ROAD PATTERNS



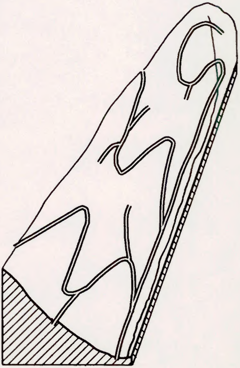
1A. PARALLEL CONTOUR ROADS. ONE CLIMBING ROAD



2. RIDGE AND VALLEY



1B. PARALLEL CLIMBING ROADS



3. RANDOM ROADS

Cascade Mountain range. Studies on 8807 acres of the H. J. Andrews Experimental Forest show that the systematic road pattern reduced the average density of roads per section from 5.59 miles of random pattern roads to 4.97 miles, a saving of 0.62 miles. The length of climbing roads in the 8 to 12 per cent range was reduced from 51.4 to 14.0 per cent. The area beyond an external yarding distance of 900 feet was reduced from 19.0 per cent to 10.6 per cent.(7/) A systematic road pattern requires long range planning of the road system for the entire drainage.

122.3 RIDGE AND VALLEY ROAD PATTERN. The ridge and valley road pattern is adapted to topography typical of areas of the Coast Range where side slopes of the main drainages are short and steep. Natural landings on the side slopes are lacking, and sandstone close to the surface of the steep slopes makes road construction expensive. The best landings and road construction conditions are on the ridges. However, to reach the ridges it is usually necessary to locate a road along the valley bottom until a point is reached where a climbing road can be located to a saddle from which ridge roads can branch out. Timber on the lower slopes has to be yarded to the valley road.

122.4 RANDOM ROAD PATTERN. The random pattern of roads is the least desirable since it usually results in greater road density, less optimum yarding, and complications in logging leave settings or other residual timber in the future. Random patterns are generally the result of short-range planning from setting to setting or from year to year. A random pattern tends to develop from a checkerboard pattern of land ownership. Coordinated planning between adjacent ownerships can avoid uneconomical random patterns. However, where natural landings are scarce or feasible road routes limited, the random pattern may be the only solution.

123 OPTIMUM ROAD SPACING

123.1 ROAD SPACING FOR HIGH-LEAD YARDING. Road spacing for high-lead yarding is determined by the applicable external yarding distance and the topography. The position of suitable landings and setting boundaries will affect the spacing. The contour road pattern spacing usually is approximately twice the external yarding distance, and logs are yarded downhill as well as uphill. Where the ridge and valley road pattern is used, the spacing is fixed by the topography. Random road patterns have little uniformity of spacing. Where the volume per acre to be yarded is lighter than usual, or road construction costs unusually heavy, it may be economical to increase yarding distance and road spacing. Although optimum road spacing computations ordinarily are not used in planning for high-lead yarding where unusual conditions are encountered, computing the optimum road spacing may furnish helpful guidance.

123.2 ROAD SPACING FOR TRACTOR SKIDDING. The optimum road spacing is achieved when variable skidding cost and spur road construction cost per M board feet are equal. For a given machine, skidding cost is affected principally by the size of the average log and the skidding distance. The spur road construction cost per M varies with the volume per acre and the area served by a road, which is determined by the road spacing. The optimum road spacing for a given set of conditions may be found graphically by plotting a break-even chart. Figure 123-1 gives an example of such a chart. The combined cost curve shows that costs are a minimum where variable skidding cost and road construction costs intersect, which is the break-even point. Other methods of computing optimum road spacing and instructions for their use are given in Chapter 240.

130 PROTECTION CONSIDERATIONS

131 FIRE PROTECTION

131.1 SETTING BOUNDARIES FOR FIRE CONTROL. For the control of slash fires or accidental fires in the clear-cut setting to protect the adjoining uncut timber, the setting boundaries should be located where the fire line can be held best. Upper boundaries preferably are located along natural fire breaks such as ridge crests, rock ledges or outcrops, and roads. Natural fire breaks for lower boundaries include streams, valley bottoms, alder type lines and roads. Where natural fire breaks are not available for upper or lower setting boundaries, benches or the more gentle slopes offer a better chance for fire control than steep slopes. Side boundaries of settings on steep slopes should run at right angles to the contour. Fires tend to run up the slope parallel to such lines and are easier to control than where the cutting line angles across the contour. Draws are undesirable as side boundaries since slash tends to accumulate in the draws.

131.2 FIRE BUFFER BELTS. Where staggered settings are clear-cut along parallel roads, adjacent corners of such settings should be separated by a buffer belt of green timber. Such buffer belts should be wide enough to prevent fire from traveling diagonally from one clear-cut setting to another. The required buffer width will depend on slope and aspect and may vary from 150 feet in width on gentle north slopes to 500 feet on steep south slopes. If possible, the buffer belts should be situated so that they can be logged economically with the leave settings. Continuous clear cutting, leaving seed blocks as practiced on private land, requires special precautions to protect the seed blocks from fire.

131.3 SIZE OF CLEARCUT. The size of the clearcut area is related to the fire hazard. The larger the slash areas, the hotter the slash fire tends to become and the more difficult the fire control. Where the fire hazard will be high, as on slopes with southern exposure or where the road through the cut-over will be used by the public, smaller settings than would otherwise be cut are advisable. In planning the logging of a section of public timber adjoining a section in private ownership which has been clear-cut to the section line, care must be taken to avoid developing large areas of contiguous slash.

132 PROTECTION FROM WIND DAMAGE

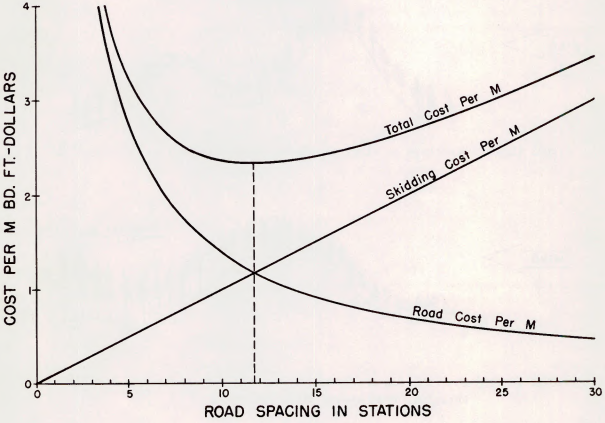
132.1 PHYSIOGRAPHIC FACTORS IN WINDTHROW. Serious losses from wind damage have occurred on the perimeter of leave settings adjacent to staggered clear-cut settings. Losses resulted mainly from breakage of trees. The storm winds which caused the greatest damage blew from the southwest quadrant (from S 20° W or S 33° W). Approximately 90 per cent of the windthrown trees were found on the north and east boundaries of clear-cut settings. Windthrow was more severe on the "lee" or sheltered side of a ridge

FIG. 123-1 CHART FOR FINDING OPTIMUM ROAD SPACING

SKIDDING DIRECT TO THE ROAD, FROM BOTH SIDES, FOR LOADING BY MOBILE LOADER.

VARIABLE SKIDDING COST $0.40 PER M BD. FT. PER STATION ROAD CONSTRUCTION COST $38.00 PER STATION. VOLUME PER ACRE CUT 12 M BD. FT.

BREAK-EVEN POINT AT 11.8 STATIONS = OPTIMUM SPACING.



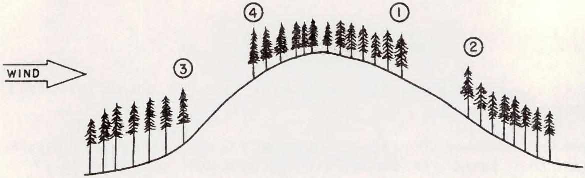


FIGURE 132-1 Relative Susceptibility to Windthrow: ① Maximum

② Medium ③ Little ④ Minimum 9/

FIGURE 132-2 Windthrow on Ridge in Lee of Higher Ridge 8/

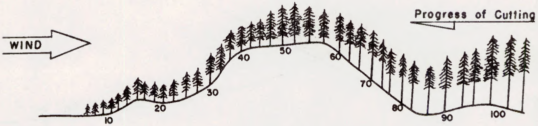


FIGURE 132-3 Distribution of Age Classes at the End of the First Rotation, Progressive Strip Cutting. 10/

than on the "windward" or exposed side. This is accounted for by "lee flow" or the tendency of wind blowing across a ridge to follow down the slope with increased velocity. (Figure 132-2) The upper third of the lee slope is the most vulnerable. Trees on small ridges or flats in the lee of a higher ridge are susceptible to windthrow. Wind velocity is accelerated by funneling through saddles or gaps in ridges, through narrowing valleys and through constricted openings or indentations cut in the stand. Trees adjoining and in the lee of such funnels are endangered. Relative susceptibility to windthrow of setting boundaries is shown in Figure 132-1. Study of the following windthrow references is recommended: Hunt (8/), Gratkowski (9/).

132.2 EDAPHIC AND BIOLOGICAL FACTORS IN WINDTHROW. Trees growing on shallow soils overlaying rock or impermeable clay or on poorly-drained soils, are shallow-rooted and very susceptible to windthrow. Skunk cabbage is an indicator of a high water table. Flats or benches at the foot of steep slopes, while appearing dry in the summer, may be saturated in the rainy season. Trees infected with root rots or butt rots are predisposed to windthrow. Poorly stocked or open stands generally are more windfirm than dense stands. Young stands usually are more windfirm and develop windfirmness faster with exposure than old stands. Hardwood stands or mixed stands of hardwood and conifers generally are wind-resistant.

132.3 SELECTION OF WINDFIRM SETTING BOUNDARIES. Consideration of the factors in windthrow indicates that wind damage can be minimized by selection of windfirm north and east boundaries of clear-cut settings. Windfirm borders are found on the windward side of ridges, on well drained deep soils, and in sound trees. Type lines of hardwoods or mixed hardwood and conifers, younger stands or open stands also present windfirm borders. Boundaries running parallel to storm wind direction are relatively safe. Avoid cutting boundaries on the lee side or crest of a ridge, on poorly drained or shallow soils, or in stands showing evidence of root rot or butt rot. Setting boundaries in the lee of natural wind funnels and V-shaped indentations in cutting lines are to be avoided. Where feasible, start cutting in the northeasterly portion of the logging unit and proceed in a southwesterly (windward) direction.

132.4 PROGRESSIVE STRIP CUTTING. Where wind damage is an appreciable hazard, progressive strip cutting in the direction of the storm wind merits consideration. Ruth and Yoder (10/) recommend a logging plan for progressive strip cutting in which the first cut is made in alternate clear-cut areas along the north boundary of the logging unit in the lee of the main east-west ridge. The second cutting sequence would take the leave areas, resulting in a long clear-cut strip. Strips would be cut in staggered settings along successively higher road levels up the lee slope of the main ridge and along successively lower levels down the windward slope. (Figure 132-3)

133 WATERSHED AND STREAM PROTECTION

133.1 FACTORS IN WATERSHED DAMAGE. Watershed damage embraces injuries to soil and water resulting from road building and yarding. Soil is disturbed by loosening and displacement or by compaction which decreases permeability. Increased surface runoff and erosion of the soil ensues.

Eroded soil carried into the streams is injurious to fish life and diminishes the water storage capacity of reservoirs. Logging slash in streams may be harmful to fish and cause downstream flood damage. The relative erosion hazard varies from "high" on light textured soils on steep slopes to "low" on heavily textured soils on gentle slopes. (Soil classifications are given in Division 600, Soil Engineering). Roads are the main factor in soil movement and stream siltation. The logging method is also a factor in erosion. Tractor skid trails on steep slopes tend to become gullies. Steinbrenner and Gessel found that soils on tractor skid roads in southwestern Washington lost 93 per cent in permeability and 53 per cent in microscopic pore space and increased 15 per cent in bulk density.(11/) The location of landings is an important factor in watershed protection. (Section 117)

133.2 WATERSHED PROTECTION-CABLE LOGGING. Care during road construction and logging and post-logging treatment are the most important elements in watershed protection. However, protection begins with the choice of cutting system and logging method. Moving cable methods are preferable to tractor logging on erosible soils on steep slopes. Clear-cut setting areas should be smaller than settings on stable soils. High-lead yarding uphill disperses the runoff along the yarding-road trails which fan out below the landing. Downhill yarding trails converge and concentrate the runoff. Landings on dry ridges or benches cause less damage than landings in draws or valleys. Where the terrain necessitates downhill yarding, skyline methods are preferable to the high-lead. Where partial cutting is the prescribed silvicultural system and steep slopes and erosible soils make tractor skidding objectionable, the new skyline methods developed for the pine region are indicated. (Article 112.2)

133.3 WATERSHED PROTECTION-TRACTOR LOGGING. Where tractor skidding is unavoidable in areas of high erosion hazard, the main tractor trails should be planned and marked on the ground. Important points in tractor trail location to minimize erosion include: grade breaks at intervals to avoid long sustained grades; crossing streams on gravel or rock beds; and avoiding trails along the bottoms of ravines or draws. Since soil disturbance is proportional to intensity of cut, light partial cuts are advisable. In some cases restriction of operations to the dry season may be desirable. A valuable guide to erosion reduction in tractor logging is reference (12/).

133.4 STREAM PROTECTION. It is becoming increasingly incumbent upon the logging planner to consider the protection of streams in the interest of downstream users. Downstream interests include fishing, recreation, water storage reservoirs for irrigation, hydroelectric power or municipal water supply, and riparian structures. They are adversely affected if logging results in sedimentation, flood debris and channel changes. Stream protection requires locating roads well back from main creek channels. Landings and setting boundaries are selected so that logs will be yarded away from fishing streams, not across them, and slash will not accumulate in streams. Natural filter strips are left between creeks and roads or cutting lines to filter the sediment carried by water flowing from disturbed areas. Observation of creeks below existing roads during heavy rains will indicate the width of filter strip required in a given locality. The width of strip required increases with steepness of slope. Trimble and Sartz (13/) recommend 2 feet of width for each 1 percent of slope added to a base width of 25 feet in northern hardwoods. Other stream protection considerations in road location are given under "Forest Road Engineering."

134 PROTECTING RECREATIONAL VALUES

134.1 SCENIC STRIPS. Where recreation is an important forest use, consideration of the viewpoint of the recreationist is important from the standpoint of public relations. The sight of cut-over land and particularly of slash-burns is offensive to many people who do not appreciate the economic contributions made by the timber harvest. It may be advisable to leave a scenic strip of natural forest between a main road and a cutting line. The scenic strip should be wide enough so that the cut-over cannot be seen from the road. Spur roads should leave the main road on a curve so that the traveler on the main road cannot see along the spur road clearing into the logging area. The protection of fishing streams also contributes to the protection of a recreational resource.

140 SILVICULTURAL CONSIDERATIONS

141 CLEAR CUTTING

141.1 PROVISION FOR REGENERATION. Forest management in the Douglas-fir region begins with the conversion of the natural old-growth forest to a managed second-growth forest through the logging of the old-growth. The provisions made in the logging plan for securing regeneration of the cut-over land affect future forest management. The silvicultural systems applicable to the lands managed by the Bureau of Land Management in Oregon are covered in detail in the Forest Management Handbook. They are referred to here only briefly as a reminder to the logging planner and to insure that silvicultural considerations are not overlooked. Generally the silvicultural system to be followed will be determined prior to the inception of planning as a matter of policy by the district manager, or unit forester. In some cases study of the logging unit may indicate the desirability of recommending a change in the customary system.

141.2 STAGGERED SETTINGS. Clear cutting by "staggered settings," also termed "patch cutting" or "area selection cutting," is the system currently favored in the Douglas-fir region by the Bureau of Land Management. The areas of the clear-cuts vary from 20 to 80 acres and are commonly 30 to 40 acres. Current policy is to limit the size of setting to a maximum of 60 acres. Areas larger than 40 acres require two landings. One or more economic settings are left between clear-cuts. Advantages of the system include the following: the logged area is surrounded by seed source for natural regeneration; the seed trees are within seeding distance of any part of the setting; areas to be slash-burned or to be protected if slash is not burned, are isolated and relatively small. Disadvantages of staggered settings, as compared with continuous clear cutting include: the high road construction cost per M board feet for the first cutting cycle, since at least twice as much road is required for the same volume of production; longer moves of yarding and loading equipment between settings; and more perimeter exposed to windthrow. Windthrow losses along the borders of staggered settings in some localities have been alarming. Natural regeneration has not always been entirely satisfactory, particularly on exposed south slopes.

The patch cutting system is especially well adapted to forests where patches of over-mature, diseased, or heavily windthrown timber are intermingled with thrifty timber; or patches of older age classes alternate with younger age classes; or where the windthrow hazard is not high. The size of the clear-cut will depend upon the timber stand, the topography, the regeneration probabilities and the volume of timber necessary to obtain an economical road construction cost.

141.3 PROGRESSIVE STRIP CUTTING. Clear cutting successive settings in long strips along a road, leaving uncut belts of timber of setting width on both sides of the strip, appears to be gaining in favor where the windthrow hazard is high. (Section 132) The width of the strip is ordinarily the width of a setting or twice the external yarding distance. It has the advantages over the staggered setting system of reducing the perimeter subject to windthrow, having only one north or east boundary exposed to the wind, reducing the length of road required in the first cutting sequence by one-half, and shortening the moving distance between landings. Disadvantages include large areas of slash and seed source on only two sides of the clear-cut. The progressive strip system is still experimental so far as the success of natural regeneration is concerned. This system is adapted to uniform stands over large areas; to relatively low volumes per acre where road construction costs are high; and where windthrow is a serious problem. The system is well suited to long slopes where the systematic parallel road pattern is feasible. Strips would be cut along alternate roads in the first cutting cycle. The width of the strip is determined by economic road spacing. A modification of this system is cutting alternate settings along the strip in the first cutting sequence and taking the leave settings in the second cutting sequence. (Article 132.4)

141.4 CONTINUOUS CLEAR CUTTING. Continuous clear cutting, leaving blocks of trees to provide a seed source for natural regeneration, is the system commonly used on private land in the Douglas-fir region. While this system is not used on O&C lands, it must be recognized that it is the prevailing system on intermingled private lands. This may affect logging plans on O&C lands. The success of the system depends upon the location of the seed blocks and their survival from slash fire and windthrow.

142 PARTIAL CUTTING

142.1 PARTIAL CUTTING IN PINE. Partial cutting or tree selection is the accepted system in ponderosa pine and other uneven-aged forest types. The marking policy is usually specified prior to the inception of the logging plan. The volume per acre to be cut is an important consideration in planning the roads. For marking rules and further information on partial cutting, refer to the Forest Management Handbook.

142.2 PARTIAL CUTTING IN DOUGLAS-FIR. Partial cutting in Douglas-fir is limited to thinnings in second-growth stands and to pre-logging and salvage in old-growth stands. Thinnings from immature stands may be "from the bottom" to remove suppressed, poorly-formed trees and dying trees for pulp-wood, small saw logs, smelter poles, etc. Thinnings "from the top" are made to obtain merchantable saw logs, poles or piling from the larger dominant or codominant trees. Such thinnings are more apt to pay for the roads, which is the major economic problem in thinning operations.

"Pre-logging" is the removal from settings to be clear-cut of the smaller understory trees which would be subject to breakage if logged with the larger overstory trees. Pre-logging of trees attacked by insects has also been done. On ground unsuitable for tractors, pre-logging is done by high-leading with a portable steel tower or with a mobile combination yarder-leader.

Salvage logging removes the scattered dead or dying trees and windfalls in old-growth stands, usually from the reserve settings which are accessible to roads. A detailed study of such logging on an experimental salvage sale has been published by Carow. (4/) Pre-logging of the white fir from a Chermes-infested forest has been successfully accomplished with the use of portable steel towers.

143 PRIORITY SEQUENCE OF CUTTING

143.1 PRIORITY IN CLEAR CUTTING. An important consideration in the selection of clear-cut settings is the reduction of loss of merchantable volume from decay and mortality. It requires the annual growth of many acres of second-growth to make up for the loss of one old-growth tree. Where variation in conditions of health and vigor are found over an operations unit, settings should be selected so that cutting can proceed in priority sequence as follows:

1. Dead or dying stands containing windthrown, fire-killed or insect-infested trees.

2. Over-mature, decadent or diseased stands.

3. Mature stands on the steeper slopes. The object is to leave the reserve settings on more gentle slopes where they can be more easily salvaged.

4. Other mature stands. The lesser-stocked open stands are generally more windfirm and more apt to survive as leave settings than dense stands.

In stands where conditions are uniform over large areas, the settings which will best facilitate construction of the permanent roads desired for fire protection, administration, etc. have priority for the first cutting sequence.

143.2 PRIORITY IN PARTIAL CUTTING. The basis of marking individual trees in ponderosa pine is the chance of survival until the next cutting cycle. In addition to trees which have already been attacked by bark beetles or by mistletoe, the high-risk trees under Keen's classification, which are susceptible to beetle attack, are marked. These are also likely to be the trees of slower growth rate. In selecting areas to be logged, those carrying the higher proportion of beetle-infested and high-risk trees have first priority.

In thinning immature Douglas-fir, first in priority is the removal of the suppressed, stagnated and slow-growing trees and those which will probably die before the next cutting cycle. Salvage logging in old-growth Douglas-fir removes only the dead or dying trees, snags and windfalls.

150 OTHER CONSIDERATIONS

150.1 SAFETY CONSIDERATIONS. By his selection of landings and setting boundaries and location of roads with the safety of the workers in mind, the logging planner can contribute to the safety of the logging operation. Safety is an economic as well as humanitarian consideration because of the high cost of industrial insurance in logging. Safety can be engineered into the logging operation. (1/) The logging plan which meets the test of all other considerations is still not the best plan if it can be changed to make the operation a safer place for men to work.

150.2 CONSIDERATION OF FUTURE CUTS. In his preoccupation with the "take" settings for the first cutting sequence, the logging planner may neglect consideration of the logging of the "leave" settings of the staggered setting system. It can be argued that future changes in logging machines and methods may make the long-range logging plan obsolete. However, this does not condone leaving settings which do not meet the physical and economic requirements of present logging methods. Of particular importance is consideration of salvage of possible windthrow or slash-fire-killed timber on the borders of the leave settings. Even though actual landings may not be available, reducing the gradient of the road at intervals to permit salvage yarding and loading with mobile machines is desirable.

The long-range logging plan which considers the logging of the entire drainage is likely to obtain better results throughout the cutting cycle than the short range plan for the current cutting sequence. The ideal to be sought is to know how the last setting in a logging unit will be reached before the first setting is sold.

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CONTENTS

200 LOGGING PLANNING

210 PREPLANNING ACTIVITIES

211 BASIC DATA ACQUISITION

211.1 POLICY INSTRUCTIONS. When the logging planner is assigned a planning project, his first step is to obtain policy instructions from his superior. Following are matters of policy which should be defined clearly:

1. The description of the project area.

2. The allowable annual cut and the volume to be cut in the first sequence.

3. The classes of roads desired and anticipated traffic other than logging traffic.

4. The silvicultural system to be used

   a. In Douglas-fir, the setting size limits.

   b. In ponderosa pine, the volume per acre to be marked.

5. The acceptable logging methods.

6. Any other special instructions.

211.2 DATA TO ASSEMBLE. The second step is to assemble all available information on the topography, timber and ownerships in the project area. The various kinds of maps, aerial photographs and timber data which may be available are listed in ensuing articles. Assemble all available logging cost data germane to road spacing, yarding distance and road construction. Supplement the logging cost data for timber appraisal in Chapter III of the Timber Sale Procedure Handbook with local cost records.

211.3 BUREAU OF LAND MANAGEMENT MAPS.

1. The Cartographic Section, Oregon State Office, Bureau of Land Management makes the following types of maps by photogrammetric methods. Some of these maps may be available for the project area.

   a. Forest type maps, scale 1 inch = 1000 feet which have been made for most of the O&C lands.

   b. Planimetric base maps, scale 1 inch = 1000 feet, showing drainage and culture.

c. Topographic maps, scale 1 inch = 400 feet, contour interval 20 feet, which presently are available only for part of the O&C lands. Such large scale maps are the most desirable for logging planning.

2. Precruise topographic and forest type maps, scale 8 inches = 1 mile, contour interval 100 feet, made by the Unit. For instructions on precruise mapping see II-3 to II-7 and Exhibits "a" to "d" of "Sale Layout," Timber Sale Procedure Handbook.

211.4 OTHER MAPS. The following small scale maps are usually available for all O&C and Public Domain lands:

1. United States Geological Survey topographic quadrangles, scale 1:62,500 or 1.014 inches = 1 mile. The contour interval of the newer maps is 40 feet or 80 feet. Enlargements of such maps to 1 inch = 1000 feet are made by the Cartographic Section, Oregon State Office, Bureau of Land Management.

2. United States Geological Survey geological quadrangles. These maps are particularly useful in road engineering. (See Division 600)

3. Forest Survey type maps by counties, published by Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

4. Metsker township maps showing ownerships.

5. Owners of intermingled private lands may have one or more of the following types of maps of their lands: aneroid topographic maps made by the cruiser; logging plan maps, road right-of-way plats. If obtainable, they are helpful for control along common boundary lines and for identifying existing roads.

6. Soil survey maps by the Soil Conservation Service or state agencies. These are usually limited to agricultural land but may be useful in planning an approach road outside the forest.

211.5 AERIAL PHOTOGRAPHS.

1. Contact prints of aerial photography for stereoscopic use are supplied by the Cartographic Section in the following scales:

   a. The larger scale 1:12,000 photographed with 12 inch lens. This scale is preferred for forest photo-interpretation. The photos are available in the district or unit files.

b. The smaller scales 1:15,840 to 1:21,000 photographed with 8.25 inch lens. Due to the greater relief displacement, photos of these scales are better for measuring differences in elevation of controlling points for road route projection. These photos can be obtained from the Cartographic Section on special order.

2. Flight index maps or mosaics for identifying the photo numbers of the contact prints. Note the date of the flight so corrections can be made for subsequent road construction or logging. Flight altitude and focal length of lens is required for photogrammetric use.

3. Controlled mosaics have been made for some areas and more will be available in the future. The mosaic is useful for giving a comprehensive picture of a drainage or unit, for planning field work, and for progress record.

211.6 LAND SURVEYS. Copies of the original field notes of the cadastral survey or resurvey showing bearings and distances between corners, the chainage at which ridges and streams were crossed on the section lines, and monument descriptions are essential to any forest engineering. If right-of-way plats or subdivision surveys have been made of adjoining private lands, efforts should be made to obtain the cooperation of the owners in supplying data on surveys of common boundary lines.

211.7 ROUTE SURVEYS. If any route surveys have been made in or near the planning area, plan and profile prints of the surveys will be very helpful for photogrammetric and survey control. The kind of route survey and the agency from which the plan and profile can be obtained follows:

Route Survey	Agency
State Highway	State Department of Highways
County Road	County Engineer
Federal Access Road	Access Section, Oregon State Supervisor, BLM
Main Forest Road	District Engineer or Unit Engineer, BLM
Private Road	Private Land Owner
Transmission Line	Bonneville Power Administration, Public Utilities Division
Pipe Line (water, gas)	Utility Owner
Micro-Wave Relay Station	Pacific Telephone and Telegraph Company

211.8 TIMBER DATA. Assemble all timber inventory data and any other cruise data on the project area. Cruise data on adjoining lands, if obtainable, are helpful in photo-interpretation. If any cutting has taken place previously in the planning area, collect any pertinent data revealed by the records, including location, area, volume and defect. Check trespass records as well as timber sale records. Check whether the cutting is shown on the maps and photos; correct if necessary. Information on defect and breakage of timber cut on other ownerships in the area may be indicative.

211.9 RECONNAISSANCE NOTES. If any reconnaissance previously has been made in the planning area, assemble the reconnaissance notes. If possible, interview the person who made the reconnaissance to learn of any special problems or difficulties which might be encountered, and to get his ideas on the development of the area. Interview others who have been in the project area for information on any noteworthy conditions such as slides, rock outcrops, blowdowns, etc.

212 PREPLANNING RECONNAISSANCE

212.1 RECONNAISSANCE REQUIRED. The amount of preplanning reconnaissance which will have to be done in the field will depend upon how much information is needed to supplement that obtainable from available maps. If the project area is covered by the 400 feet-to-the-inch scale topographic maps, less reconnaissance is required than if only small scale maps are available. Some reconnaissance is always needed to ascertain any changes in stand condition as type-mapped, such as windthrow or beetle-kill. Conditions affecting road routes, such as rock outcrops and unstable soil, may not appear on the topographic map. If a precruise map is used which was made by other than the logging planner, it is desirable to walk over the area, particularly at road control points and landings, to become familiar with the area and to check the accuracy of the map. Reconnaissance for road routes is covered in detail in Chapter 420.

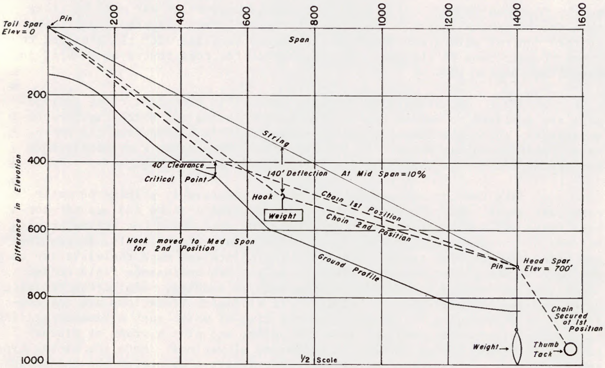
212.2 RECONNAISSANCE FOR PHOTOGRAMMETRIC PLANNING. Some individuals are inclined to depend too much on aerial photos and shirk field reconnaissance. Where the timber stand is dense, much is hidden from the photo-interpreter which may affect the logging plan. Considerable reconnaissance and ground control is essential for photogrammetric planning.

Take the contact aerial photographs, preferably printed on water-resistant paper, into the field. Pin-prick section corners and quarter corners found and any bench marks or triangulation stations. Get altimeter elevations of corners and of other identifiable points along trails, in openings and along any existing roads. Pin-prick the points and mark the elevation on the back of the photo or cross reference on the reconnaissance field notes. Elevations of obvious controlling points such as saddles, main stream crossing sites and benches will also be helpful. If altimeter elevations are not controlled by a recording barograph, note the time at which each altimeter reading is made, close on the starting elevation point, and plot a graph of diurnal barometric change for adjustment of altimeter elevations. Note the timber types and conditions of the stand as they affect priority sequence on the photograph and mark in grease pencil using the standard type symbols.

Better photogrammetric control is obtained by running a traverse through the area with a staff compass, steel tape and Abney level. The traverse is usually run where it can be done most easily and quickly. If a good trail exists, traverse along the trail. A desirable pattern is to traverse up the bottom of the main valley and along the crest of the main ridges, connecting them to the valley traverse for a closed circuit. Tie the section lines and the corners near the traverse.

7. The maximum tension and the factor of safety may then be calculated by one of the methods given in Article 231.3. If the tension exceeds the desired factor of safety with a load of the largest log or the desired size turn, change the position of head tree or tail tree to increase the deflection. If adequate deflection cannot be obtained, the trial skyline location cannot be used.

FIGURE 231-1 DEFLECTION CHART



P L E A S E N O T E

231.2 DEFLECTION CHART

Step 7 appears at the top of page 36

220 LOGGING PLAN MAPPING

221 LOGGING ENGINEERS' METHOD

221.1 ADVANTAGES. In areas of rough topography where logging is difficult and road construction costs high and where timber values make the mapping cost economically feasible, the method described in this section is used by logging engineers in industry. The description of this method may suggest application in Bureau of Land Management pre-cruise mapping. Where the forest cover is dense, with few openings where the ground can be seen, this method results in a better map than can be obtained with photogrammetric methods. It also has the advantage of leaving numbered tags at chaining points, which are shown on the map, to tie in road surveys and setting boundaries. Topographic mapping is combined with cruising to give a complete, detailed, accurate logging plan map.

221.2 BASE LINES. Base lines are run along parallel section lines with staff compass and 200 or 300 foot tape; generally parallel to the main drainage so that strip lines will cross the contours. Elevations are taken with double Abney level or hand level and rod. Base lines are connected with tie lines run along one or both perpendicular section lines. Stakes are set at chaining points.

221.3 STRIP LINES. Strip lines are run between base lines with staff compass tape and Abney level by a two-man party. A numbered aluminum tag is set in a tree or highpole at each chaining point. The strip interval depends upon the visibility for mapping and the percentage cruise desired. Usually 16 strips per section are run. After adjustment of errors of closure of the strip line, the chaining points are plotted to scale on 10 x 10 cross-section paper with the tag number and elevation. Scales used include 200, 300, 330 and 400 feet to the inch.

221.4 TOPOGRAPHY. The topographer follows the strip line and draws on the paper strip 20 foot contours and other topographic features as he sees them from each tagged point. Bearings of ridges and creeks are obtained with a hand compass, and side slopes are measured with the Abney level. Possible controlling points off the strip line are plotted by pacing and hand compass, and elevation is obtained with the Abney level.

221.5 CRUISING. The cruiser follows the strip line, cruising the timber, and drawing type lines on a duplicate of the plotted paper strip. Notes on soils and rock affecting road construction and logging are taken by the best qualified man in the party.

221.6 MAP COMPILATION. The topographic strips are pasted on a "base map" or plot of the base lines. A pencil tracing of the topography is made. Any error of closure of contours along the edges of the strips is corrected in drawing the tracing. Numbered tag points are traced. The timber type strips are similarly pasted on a base map, the map tracing laid over it and the type lines traced. Cruise data may be added to the map. Finally, white prints are made from the pencil tracing for use in logging planning.

230 PLANNING FOR SKYLINES

231 DEFLECTION AND TENSION

231.1 IMPORTANCE OF DEFLECTION. In planning for skylines the main problem is to obtain adequate deflection or sag in the skyline so that the tension in the cable will not exceed the desired factor of safety. The minimum factor of safety generally used by logging engineers is 3, although the tables in the wire rope manufacturers' handbooks use a factor of safety of 5. A factor of safety of 3 means that the tension is one-third of the breaking strength in the skyline. Tension is a maximum at the upper support when the load is at mid-span. The logger's rule of thumb is that deflection should not be less than 5 percent of the span, which is the horizontal distance between head tree and tail tree. Steep slopes require more deflecttion, and the tension should be computed.

Landings for skylines on steep slopes should be located well back from the bottom of the slope. In some cases it may be necessary to put the landing on the other side of the valley to obtain deflection. Where clearance for deflection is doubtful, draw a profile of the skyline road taken from a topographic map or from an Abney leveled and chained line over the proposed skyline road.

231.2 DEFLECTION CHART. Following is a graphic method of determining deflection:

1. Plot a profile of the ground between head and tail trees on 10 x 10 cross-section paper using a scale of 1 inch = 100 feet for both vertical and horizontal axes.

2. Fasten the paper to a wall with the horizontal lines level.

3. Put pins at the estimated elevations of the skyline supports (tree shoes) above the ground.

4. Stretch a string straight between pins and hang a light chain over the pins. The chain will assume the profile of the skyline, which is a catenary.

5. Hang a light weight with a wire hook on the chain to represent the load and adjust the sag in the chain to give a clearance of 20 to 30 feet from the ground at the critical point on the profile.

6. Anchor the chain with a thumb tack and move the load to mid-span. Scale off the vertical distance between the string and the chain at mid-span. This is the deflection in feet.

231.3 COMPUTING TENSION. The tension in skylines may be computed by using the formulas in the handbooks published by the wire rope manufacturers. They are available without charge from wire rope distributors. The quickest method is to use the following tables reproduced by permission of Professor William A. Davies, Forest Engineering Department, School of Forestry, Oregon State College. (1/) To facilitate computation, use units of Kips (1000 pounds) for loads and tensions and stations (100 feet) for spans. Span is horizontal distance between head and tail trees.

TENSION IN KIPS DUE TO 1 KIP OF LOAD

Slope %	Deflection in Per Cent of Span 5	6	7	8	10
0	5.02	4.15	3.60	3.15	2.54
10	5.00	4.12	3.56	3.11	2.50
20	5.02	4.13	3.57	3.10	2.49
30	5.09	4.17	3.60	3.12	2.50
40	5.22	4.26	3.68	3.17	2.54
50	5.39	4.40	3.79	3.27	2.60
60	5.58	4.57	3.92	3.38	2.68
70	5.81	4.77	4.08	3.51	2.79
80	6.10	5.00	4.27	3.68	2.91
90	6.40	5.25	4.48	3.87	3.04
100	6.72	5.52	4.70	4.07	3.19

BREAKING STRENGTH IN KIPS
1 W.R.C. Cable

Diam. Inches	Plow Steel	Improved Plow Steel
1-1/2	172	198
1-5/8	200	230
1-3/4	232	266
1-7/8	264	342

TENSION IN KIPS PER STATION OF SPAN DUE TO WEIGHT OF CABLE

Slope %	Deflection Per Cent 5	6	7	8	10	Deflection Per Cent 5	6	7	8	10
	1-1/2 Inch Cable					1-5/8 Inch Cable				
0	1.01	0.85	0.74	0.65	0.54	1.19	1.00	0.87	0.76	0.64
10	1.04	0.88	0.77	0.68	0.57	1.23	1.04	0.90	0.80	0.68
20	1.09	0.92	0.81	0.72	0.60	1.28	1.08	0.96	0.84	0.70
30	1.16	0.98	0.86	0.77	0.64	1.36	1.15	1.01	0.90	0.76
40	1.25	1.06	0.93	0.83	0.70	1.47	1.24	1.09	0.98	0.82
50	1.38	1.16	1.01	0.90	0.76	1.59	1.36	1.19	1.06	0.89
60	1.49	1.26	1.11	0.99	0.83	1.75	1.48	1.31	1.16	0.98
70	1.64	1.18	1.22	1.09	0.91	1.92	1.63	1.43	1.28	1.08
80	1.90	1.53	1.34	1.20	1.01	2.11	1.80	1.58	1.41	1.19
90	1.99	1.69	1.48	1.33	1.11	2.33	1.98	1.76	1.56	1.30
100	2.20	1.88	1.64	1.47	1.23	2.58	2.21	1.92	1.73	1.44
	1-3/4 Inch Cable					1-7/8 Inch Cable				
0	1.38	1.18	1.01	0.88	0.74	1.58	1.33	1.16	1.02	0.85
10	1.42	1.20	1.04	0.92	0.77	1.63	1.38	1.20	1.06	0.88
20	1.49	1.28	1.10	0.96	0.82	1.71	1.44	1.26	1.12	0.94
30	1.58	1.33	1.17	1.05	0.88	1.81	1.53	1.34	1.20	1.01
40	1.70	1.44	1.26	1.13	0.95	1.95	1.65	1.45	1.30	1.09
50	1.85	1.58	1.38	1.22	1.03	2.12	1.81	1.58	1.41	1.18
60	2.02	1.73	1.51	1.34	1.13	2.32	1.97	1.74	1.54	1.30
70	2.22	1.88	1.66	1.48	1.25	2.56	2.17	1.91	1.70	1.43
80	2.45	2.08	1.83	1.63	1.37	2.81	2.39	2.10	1.87	1.57
90	2.70	2.30	2.02	1.81	1.53	3.10	2.64	2.31	2.08	1.74
100	2.99	2.55	2.23	2.00	1.67	3.43	2.94	2.56	2.30	1.92

EXAMPLE: Given 1-7/8 inch I.P.S. cable, breaking strength 343 Kips, trial span 14 stations on 50 percent slope. To clear critical point, deflection at center, Dc = 70 feet = 5 percent of span. Loads in Kips: carriage 1.2, fall block and rigging 14.6, turn of logs 28.8. North Bend system so half the fall block and turn stresses the skyline.

Load, P, = 1.2 + 14.6/2 + 28.8/2 = 22.9 Kips;
Tension due to cable, Tw = 2.12 x 14 = 29.7 Kips;
Tension due to load, Tp = 5.39 x 22.9 = 124.5 Kips;
Total T = 154.2 Kips. Factor of Safety, FS = 342/154.2 = 2.22
Desired FS = 3.

By moving head tree 2 stations out from toe of slope, Dc reduces to 112 feet or 7 percent; slope reduces to 45 percent; span increases to 16 stations. Interpolate in table for Tw per station and Tp per Kip of P. Then,

Tw = 1.51 x 16 = 24.2;
Tp = 3.73 x 22.9 = 85.4;
T = 109.6;
FS = 342/109.6 = 3.12

Therefore, move landing and road 2 stations out from trial location.

240 OPTIMUM ROAD SPACING

241 METHODS OF COMPUTING

241.1 FACTOR METHOD. Several methods of computing optimum road spacing have been developed which are faster than plotting a break-even chart. (Section 123) The simplest is the factor method developed by Pope in 1954 when he was a forester for the Bureau of Land Management. (2/) However, its use is limited to the pine region or to unsurfaced roads in the Douglas-fir region since factors are only given for road costs up to $100.00 per station.

TABLE OF FACTORS

M bd. ft. per acre V	Skid Cost per M per Station C	Factor Fv or Fc	Road Cost per Station r	Factor Fr
10	$ .10	1.00	$ 10.00	1.00
20	.20	.71	20.00	1.41
30	.30	.58	30.00	1.73
40	.40	.50	40.00	2.00
50	.50	.45	50.00	2.24
60	.60	.41	60.00	2.45
70	.70	.38	70.00	2.65
80	.80	.35	80.00	2.83
90	.90	.33	90.00	3.00
100	1.00	.32	100.00	3.16

1-way skidding (from one side of the landing) constant $K_1 = 8.52$
2-way skidding (from both sides of the landing) constant $K_2 = 12.05$

Optimum Road Spacing in Stations $S = K \times Fv \times Fc \times Fr$

Example: $K_1 = 8.52$; $V = 10$ M; $Fv = 1.00$; $C = \$.44$; $Fc = .50$;

$r = \$90.$; $Fr = 3.00$; Then $S = 8.52 \times 1.00 \times .50 \times 3.00 = 12.8$ Stations

241.2 RATIO METHOD. The most comprehensive method of computing optimum road spacing is the ratio method developed by Wallace (3/) based on formulas originated by Matthews (4/). The ratio method has the advantage of readily determining the effect on road spacing and on road, skidding and landing costs of various landing spacings expressed as a percentage of road spacing. Skidding data are for rectangular settings. Pope's factor method is for a fixed landing spacing equal to road spacing and does not take landing costs into account.

RATIOS FOR ROAD SPACING AND SKIDDING, ROAD AND LANDING COSTS

When landing spacing Z in percent of road spacing S is 12.5 for 2-way skidding and 25 for 1-way skidding

Z for 2-Way Skid	Skid and Road Cost Ratio	Landing Costs Ratio	S (Road Spacing) Ratio	Ratio of Decrease in Landing Cost to Increase in Skid and Road Costs	Z for 1-Way Skid
1	2	3	4	5	6
20	1.012	.640	.989	41.00 to 1	40
30	1.031	.443	.970	14.00 to 1	68
40	1.054	.346	.949	5.80 to 1	80
50	1.079	.291	.926	2.90 to 1	100
60	1.106	.254	.904	1.80 to 1	120
70	1.135	.230	.881	1.20 to 1	140
80	1.165	.213	.858	0.75 to 1	160
90	1.195	.199	.837	0.67 to 1	180
100	1.227	.189	.815	0.40 to 1	200
150	1.418	.168	.705	0.14 to 1	300
200	1.689	.179	.582	0.05 to 1	400

A. For 2-way skidding (from both sides of landing) Z = 12.5 rectangular setting.

1. Compute road spacing S in stations of 100 feet. $S^1 = \sqrt{\frac{17.116\ r}{VC}}$

   Where r = road construction and maintenance cost per station; V = M board feet per acre; and C = variable skidding cost per M board feet per station.

2. Compute road cost per M board feet = $\frac{4.356\ r}{VS}$

3. Compute skidding cost per M board feet = 0.2545 CS

4. Compute landing cost per M board feet. = $\frac{L}{0.0287\ VS^2}$ Where L = landing expense

5. Compute ratio of decrease in landing cost to increase in skidding

   cost = $\frac{\text{road cost + skidding cost}}{\text{landing cost}}$

6. Find nearest ratio in Column 5 and read corresponding Z value in Column 1.

7. Multiply S computed in Step 1 by ratio for new Z (Step 6) from Column 4.

8. Multiply costs computed in Steps 2, 3 and 4 by ratios for new Z from Columns 2 and 3.

B. For 1-way skidding (from one side of landing only) Z = 25 rectangular setting.

1. Compute $S = \sqrt{\frac{8.558\ r}{VC}}$

2. Compute road cost from same formula as under A, Step 2.

3. Compute skidding cost = 0.509 CS

4. Compute landing cost = $\frac{L}{0.0574\ VS^2}$

5. Compute ratio in the same way as under A, Step 5.

6. Find nearest ratio in Column 5 and new Z in Column 7.

7. Same as Step 7 under A.

8. Same as Step 8 under A.

C. To find S and costs for any other Z, multiply by quotient of

$$\frac{\text{S for ratio in Column 4 for another Z}}{\text{S for ratio in Column 4 for previous Z}}$$

Example of computations by Method B: Given r = \$90.00 per station; V = 10 M board feet per acre; C = \$0.40 per M board feet per station; L = \$300.00 1-way skidding.

1. $S = \sqrt{\frac{8.558 \times 90}{10 \times .40}}$ = 13.9 stations for landing spacing 25 percent of S

2. Road cost = $\frac{4.356 \times 90}{10 \times 13.9}$ = \$2.82 per M board feet

3. Variable skidding cost = 0.509 x .40 x 13.9 = \$2.83 per M board feet

4. Landing cost = $\frac{300}{0.0574 \times 10 \times 13.9^2}$ = \$2.70 per M board feet

5. Ratio = $\frac{2.82 + 2.83}{2.70}$ = 2.1

6. Nearest ratio in Column 5 is 1.8.

   Z for 1.8 is 120 percent of S
   Ratio for S = 0.9039 new S = 13.9 x 0.904 = 12.6 station
   Ratio for road cost and skidding cost = 1.1063
   Ratio for landing cost = 0.2545
   Road cost = 2.82 x 1.106 = \$3.12
   Skid cost = 2.83 x 1.106 = 3.13
   Landing cost = 2.70 x 0.254 = 0.69
   Total \$6.94

   Therefore use S of 12.6 stations and landing spacing of 15 stations.

250 PLANNING ON LARGE SCALE MAPS

251 DOUGLAS-FIR REGION PLANNING

251.1 PLANNING PROCEDURES. The best planning for logging in rough topography in the Douglas-fir region, where the high-lead is the principal yarding method and good landings are scarce, can be done when accurate large scale topographic maps are available. Experience has demonstrated that efficient procedure is to follow the consecutive steps given below in Articles 251.2 -- 251.9. Planning may be done either directly on the map print or on a cellulose acetate overlay.

Before proceeding with the detailed planning, it is advisable to review Division 100, "Considerations in Logging Planning." Outlining the specific considerations applicable to the planning project will help to avoid overlooking any consideration. Also review Chapter 320, "Considerations in Route Selection" and Section 411, "Route Projection on Large Scale Maps."

251.2 PRIORITY AREAS. The first step is to delineate in brown the boundaries of first priority areas. (Article 143.1) If a type map is available, transfer priority areas onto the topographic map. Otherwise, take the priority areas from the aerial photographs and plot on the logging plan map by correlating with topographic features.

251.3 TRIAL LANDINGS. The second step is to select the trial landings in the following manner:

1. Mark with a penciled "X" the possible natural landings. Mark the landings in the priority areas first. Then mark possible landings in the other areas.

2. With a pencil compass set at the external yarding distance indicated for the conditions, draw circles around the landings.

3. Some of the circles will overlap. Others will be too far apart. Select the landings which are properly spaced and complete the penciled high-lead landing symbol thus: Ⓧ

4. Delineate any ground suitable for tractor yarding and mark the tractor landing symbol ☐ at a possible landing at the lower edge of the tractor area.

251.4 TRIAL ROADS TO LANDINGS. The third step is to find out which of the trial landings can be reached by a truck road within the allowable gradient limit for the class of road specified.

1. Determine from information on existing roads where the road will enter the planning area.

2. Find the road gradients between adjacent settings as follows:

Scale the distance between settings, or with dividers step off the distance along the contours. Divide the difference in elevation read from the map by the distance to get the average gradient. Note any controlling points between settings which will affect road gradient.

3. Circle in color the accessible landings which can be reached with a road without exceeding the allowable gradient for the class of road contemplated.

251.5 ROAD PROJECTION. The fourth step is to try to find a definable systematic pattern of roads which will connect the landings. See Section 411 for the procedure to follow in projecting road routes on large scale maps. If a road from landing to landing is not feasible, consider the use of the stub spur terminating at a landing. However, care must be taken that yarding is not thus made more difficult or settings odd-shaped. Avoid yarding across a truck road.

251.6 COLD DECKS AND SWINGS. The landings which were eliminated from consideration for direct yarding should now be considered for cold-decks and swinging. If there is any doubt as to whether adequate deflection can be obtained for a skyline swing, measure the distance between ground breaks, read the elevations and plot a profile of the proposed swing road on the deflection chart. (Article 231.2) Change the position of the cold-deck or the head tree landing as necessary to obtain the deflection required.

251.7 SETTING BOUNDARIES. The final step in making the projected paper logging plan is to mark the setting boundaries. Study the topography where the yarding distance circles intersect and along the boundaries of the first priority areas, and draw the setting boundaries in conformity with the physical requirements of the yarding method to be used (Chapter 110) and the selection of windfirm setting boundaries(Article 132.3). Use contrasting colors for high-lead setting boundaries and for tractor setting boundaries. Study of the setting boundaries may indicate the desirability of some changes in landings. Adjust the landings and setting boundaries until the best plan is achieved.

251.8 FIELD CHECKING. The amount of checking of the validity of the plan required in the field will depend upon the precision of the map. Maps made by the logging engineers' method with topography drawn on the ground (Section 231) are quite dependable, and little, if any, field checking prior to the sale layout is needed. The following field checking of plans made on photogrammetric maps usually is required:

1. Run Abney level grade line along the projected road routes. This is to ensure that no obstacles or controlling points, which may have been hidden from the photogrammetrist, are encountered. Follow the instructions given in Section 423, "Reconnaissance for Projected Route." Flag the grade line for the guidance of the road survey party.

2. Check the landings selected to ensure that they meet the requirements of Section 117, "Landings."

251.9 FINAL PLAN. Following the field check, make any corrections indicated in the projected roads, landings or setting boundaries. Mark the settings in cutting sequence in order of priority with Roman numerals and formulate recommendations for sales. Trace the settings approved for preparation for sale and the roads to be constructed to them on a print of the map to be taken into the field to guide sale layout. There may be minor changes in the projected setting boundaries in the field, particularly to reduce wind damage hazard. After the field layout is completed, plot the final setting boundaries on the logging plan map.

252 PINE REGION PLANNING

252.1 PLANNING FOR TRACTOR SKIDDING. In planning for tractor skidding operations on moderate slopes in pine types where finding landings is not a problem, the paper plan is based primarily on the road system. It is essential to know the volume per acre to be cut and variable skidding and road construction costs. Calculate the optimum road spacing and landing spacing as a guide. (Chapter 240)

252.2 STEPS IN PLANNING.

1. Delineate priority areas. (Article 143.2)

2. Rough out a systematic parallel road pattern which best fits the topography. Generally the lower road will follow the valley at the lower edge of the slope but far enough from the stream to afford stream protection. The upper parallel roads will follow the benches or gentler slopes which are nearest to optimum spacing distance.

3. Project the roads on the logging plan map. (Section 411)

4. Select landings along the road at intervals which are in economic accord with the road spacing. Even though tractor skidding trails are not projected, keep in mind their pattern for watershed protection, as this will have a bearing on landing location.

5. Field check the projected roads and landing. The intensity of the field checking required will depend upon the accuracy of the map available.

6. Correct the paper plan as indicated by the field check.

252.3 PLANNING FOR CABLE LOGGING. The increased use of cable logging systems in the pine region on erosible soils and steep slopes calls for careful planning to avoid damage to the residual stand. The portable spar and the mobile combination yarder-leader permit closer landing spacing in order to high-lead perpendicular to the contour. Skyline deflection is less of a problem with the gravity systems, since they can use intermediate supports. The lower terminus must be engineered to land the turn safely.

260 PLANNING ON PRECRUISE MAPS

261 DOUGLAS-FIR REGION PLANNING

261.1 PLANNING PROCEDURE. The same consecutive steps as given under Section 251 are followed. However, due to the large contour interval, smaller scale, and some of the distances being paced, the trial plan cannot be as detailed as on the large scale photogrammetric maps. More reliance must be placed on stereoscopic study of aerial photographs to find landings not spotted in making the precruise map and other controlling points. If the original precruise map is used, do the planning on a cellulose acetate overlay.

261.2 FIELD CHECK. More field checking to determine the feasibility of the plan made from a precruise map is required. Landings are located and checked using hand compass and pacing. Since road gradients cannot be determined accurately from the precruise map, the following procedure is suggested for tagging a grade line between landings: Obtain altimeter or aneroid elevation of first landing. Pace the distance to the second landing, following an approximate gradient indicated by the map. Note the precaution given in Section 423 to avoid pacing too long rounding ridges or valleys. Read the elevation of the second landing and divide the difference in elevations by the distance to get the gradient in percent. Set the Abney on that gradient and tag the grade line back to the first landing. If the grade line hits too high or too low, note the error in feet and the correction in gradient percent required, for guidance in running the road traverse. If controlling points are encountered between landings, record the elevation and distance and work out the grade line between controlling points and landings.

261.3 CORRECTING THE PRECRUISE MAP. After the final layout is made, use the field notes of the traverses of the roads and the settings laid out for the first cutting sequence to correct the precruise map. This will enhance the utility of the map in planning setting boundaries for later sales.

270 PHOTOGRAMMETRIC PLANNING

271 DOUGLAS-FIR REGION

271.1 USE OF AERIAL PHOTOS. In the absence of logging plan maps, it is possible for a person with some skill in photo-interpretation to reduce the amount of field work, that would otherwise be required, by using aerial photos for planning. Following the reconnaissance (Article 221.2) preferably made by the person who is to do the planning, the consecutive steps given in ensuing Articles 271.2 to 271.6 are suggested. Refer also to Section 231. Concurrent use of forest type maps or of planimetric maps showing streams and culture on the same scale as the photos will expedite the work. Bear in mind that the photograph is not a map and images are displaced relative to their true map position.

271.2 PREPARATION OF PHOTOS. If the photos show an existing road for which plan and profile is available, mark identifiable elevations and distances on the photos. If traverses were run, mark coordinates and elevations of pricked points. Draw boundaries of first priority areas. Windthrown and beetle-killed areas are easily identified. Observation of the timber during the reconnaissance will help in photo-interpretation of overmature or decadent stands. Recording average tree heights at identifiable points on the photos will help in calculating ground elevations. Trees are often taller in the valleys than on the ridges.

271.3 LANDINGS. Study the photos under the stereoscope to find natural landings. Mark them with an "X" on a cellulose acetate overlay sheet. Mark landings in first priority types first. Then mark landings in intervening areas to be cut in later sequences. Mark visible road controlling points along the route between landings.

271.4 ROADS. Calculate the difference in elevation, distances between landings and controlling points, and the approximate gradients between them. Check the spacing of landings and eliminate landings which cannot be reached with a road or are not required. Mark acceptable landings with (X) . Methods of determining elevations and distances are given in Section 412, "Route Projection on Aerial Photos." The method used will depend upon the equipment available and the skill of the photo-interpreter. With the landings and calculated road gradients as a guide, outline the road pattern which best fits the conditions.

271.5 SETTINGS. Since setting boundaries can be determined only approximately from aerial photos, rough them in on the overlay without spending too much time on them. The cutting lines will have to be determined by trial in the field.

271.6 FIELD CHECK. Since the dense crown cover in Douglas-fir forests hides the ground, more field checking is required than with logging plan maps. Landings may be found which were not apparent on the photographs. Hidden controlling points affecting road locations are often found. Changes in the logging plan will usually be necessary. The "field check" is often the first stage of the field layout of the logging plan. The procedure for field checking plans made on precruise maps is suggested. (Article 261.2)

272 PINE REGION

272.1 UTILITY OF PHOTOS. Open pine stands are particularly well adapted to photogrammetric logging planning. Since more of the ground can be seen between the tree crowns, elevations can be determined more accurately than in Douglas-fir; and controlling points are more evident. Logging plan maps are seldom made in pine types since aerial photos are available. The basis of planning for tractor logging in pine, where landings are not a problem, is the road spacing and pattern. The steps in planning are outlined in Section 252.

280 FIELD LAYOUT

281 SETTING LAYOUT IN DOUGLAS-FIR

281.1 LANDINGS. When the settings planned for timber sales have been selected and approved, the landings and settings are established on the ground. This section is supplemental to the instructions in Chapter II, "Sale Layout," Timber Sale Procedure Handbook. The landing is first located as a center for the setting boundary layout. To ensure that trees suitable for spars or dummies for raising spars are not felled with the road right-of-way timber, mark them with a big "X" chopped in the bark. This means to the faller, "Do not cut." Select the largest, tallest, soundest, straightest Douglas-fir trees for spars. If possible, mark two or more in case any have hidden defects from conk rot.

Locating the road on the landing in the correct position with respect to the spar tree is important. Set a blazed and flagged highpole 8 to 10 feet from the selected spar site to mark the center line of the road for the guidance of the road engineer.

281.2 SETTING BOUNDARIES. Because of the importance of windfirm boundaries of staggered settings, the final determination of cutting lines must be done in the field. It is desirable to first make a reconnaissance of the cutting lines planned. Using a hand compass and pacing, trace the setting boundaries shown on the logging plan map on the ground. Tag or flag the trial line at intervals for guidance in running the final line. Note on the map any desirable changes in the line.

Establish the final setting boundaries in accordance with the instructions in II-B, "Area Computation and Mapping of Layouts" and II-D, "Marking Setting Boundaries" of the Timber Sale Procedure Handbook.

Location of the roads to the landings is covered in Division 500, "Road Location Surveys" of this Forest Engineering Handbook. The road engineer should also locate a turn-around for log trucks outside the guy line circle. The minimum turning radius of the typical log truck carrying the trailer is 45 feet.

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3. Wallace, Oliver P., "Ratios for Determining the Economic Road and Landing or Skidding Spacing," Journal of Forestry, 55(5) 378-9, May 1957
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CONTENTS

300 CONSIDERATIONS IN ROAD ENGINEERING

310 ROAD STANDARDS

311 O&C ROAD STANDARDS

311.1 PERMANENT ROADS. The Bureau of Land Management has standardized three classes of permanent roads for O&C lands. Following are the specifications adopted June 18, 1959:

ROAD CLASS	I	II	III
Surface Width	24 Feet	20 Feet	12 Feet
Maximum Favorable Grade	8%	10%	10%
Maximum Adverse Grade	6%	7%	7%
Maximum Degree of Curve	30°	38°	76°
Minimum Radius of Curve	190 Feet	150 Feet	75 Feet

Variations from standard Class III roads: Increase in grades above the standard may be permitted only after a detailed economic analysis proves the practicability of the proposed increase.

Typical cross-sections are shown in Figure 311-1.

While not specified, the following additional minimums are recommended:

Sight distance on vertical curve: Class I, 400 feet; Class II, 300 feet; Class III, 250 feet.

Turnouts, Class III: all blind curves and additional turnouts so spacing will not exceed 750 feet.

Widen inside of curve: 400 feet divided by radius of curve.

Up to 1960 only one Class I road, the Smith River road, has been built on O&C lands. Only exceptionally heavy public use, as well as a large annual volume of log traffic, will justify a Class I road.

The Class II road is a two-lane road adapted to situations where considerable public use for recreation, mining or farming is anticipated as well as annual log traffic. A modified Class II road, with Class III curvature and gradient limits, may be approved where rough topography engenders heavy construction and the modification is economically justified.

The Class III road is the common class of permanent road built on O&C lands. It is used for the main access road, for the branch timber sale road, and for the logging spur which is to be permanently maintained. It may be used only periodically for log hauling but is maintained for fire protection, administration and recreational use.

311.2 TEMPORARY ROADS. No specifications for temporary roads are prescribed by the state supervisor. However, for safety the following limits are recommended for temporary logging truck roads:

Maximum Grade, wet weather log hauling	15%
Maximum Grade, dry weather log hauling	18%
Maximum Degree of Curve	88°
Minimum Radius of Curve	65 Feet

The temporary road ordinarily will be a spur to a landing. It will be obliterated and the land returned to timber production when log hauling is completed.

If the location of the temporary road is left to the logging operator, measures to minimize damage to resources should be specified.

312 DETERMINATION OF ECONOMICAL ROAD STANDARD

312.1 ROAD COST DATA. The main factors determining the standards for a road are road construction and maintenance costs and log trucking cost. Traffic density is a factor only if heavy non-logging traffic is expected. The following road cost data for the various standards under consideration are required:

1. Road Construction Cost. If a P-line traverse has been run, accurate cost estimates may be made from the road design data. If the route has been projected on a large scale map from which side slopes can be measured, or a tagged reconnaissance line has been run and side slopes and excavation materials recorded, a rough estimate of comparative costs may be made as follows:

    a. Clearing and Grubbing. Read acres per mile for the side slopes from Figure 6, reference(1/). From cruise data or from observation of density of stand along reconnaissance line, estimate volume per acre and cost per mile of clearing and grubbing.

    b. Grading. Read cubic yards per mile for the side slopes from Figure 5, reference (1/). Multiply the yardage for each class of material by the current cost per yard of excavation.

    c. Drainage Structures. Estimate the number and average size of culverts, the total lineal footage and compute the cost installed. The only difference in drainage costs between two widths of road will be in culvert lengths. Add the cost of bridges based on local experience.

    d. Surfacing. Compute the volume of surfacing rock for the depth of base course and wearing surface required by the subgrade soils. (Chapter 630) A Class II road will

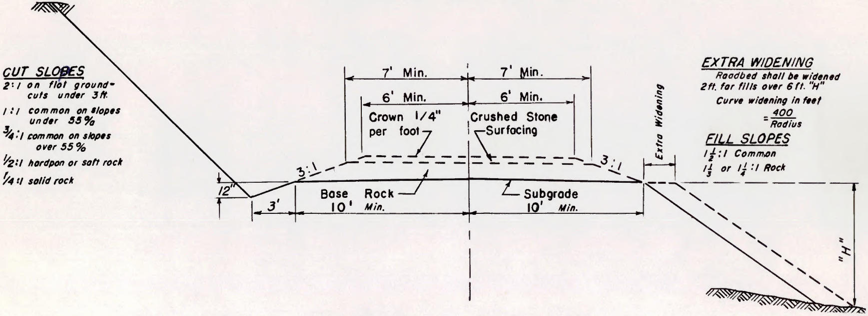
FIG. 311.1

U. S. DEPARTMENT OF THE INTERIOR

BUREAU OF LAND MANAGEMENT

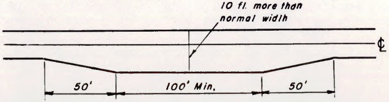
CLASS III ROAD

TYPICAL CROSS SECTION



PLAN OF TURNOUTS

Turnouts shall be constructed on all blind curves with additional turnouts as needed to keep spacing below 750'



require 1564 cubic yards per mile per foot of surfacing depth more than a Class III road. Apply rock costs from Chapter III-H, Timber Sale Procedure Handbook.

2. Road Maintenance Cost. The annual cost per mile of road maintenance is best obtained from local experience on comparable roads. Maintenance cost tends to increase on steeper grades and sharper curves. It is also affected by volume of traffic.

312.2 LOG TRUCKING COST DATA. The average cost per round-trip of mile of hauling logs over the road is required. From the road design from a P-line, truck travel time may be calculated accurately using the data in reference (2/). From the same reference, the cost of truck operating time per minute plus the cost of tires per mile can be used to find hauling cost. Apply the current cost index to bring costs up to date.

If the trucking cost estimate is based on a reconnaissance line or a route projection, the tables given in Section 331 will enable comparative travel time on roads of various standards to be computed. For empty truck increase travel time 1.5 percent for each five vehicles of traffic per hour for waiting at turnouts. Convert travel time to cost by applying the best available truck operating cost data. If it appears that travel time on a segment of road will be controlled by gradient, use Table 331-1 or 331-2. If curvature will control, use Table 331-3 or 331-4.

312.3 ANNUAL COST FORMULA. The determination of the most economical road standard is based on a comparison of combined annual costs of road construction, road maintenance and log trucking. The formula for annual cost is:

$$A = R + I + M + T$$

Where A is total annual cost in dollars per mile; R is the annual cost of road construction for the amortization period; M is annual road maintenance cost per mile; and T is average log trucking cost per mile for the annual log volume to be hauled out over the road.

Example: Assume the following costs have been estimated for three classes of road. Annual volume, 10 million board feet.

ROAD CLASS	I	II	III
Construction Cost per Mile	$40,000.00	$22,000.00	$15,000.00
Maintenance Cost per Mile	300.00	400.00	500.00
Trucking Cost per M Bd. Ft. per Mile	.25	.30	.35
Trucking Cost per Annum Per Mile	2,500.00	3,000.00	3,500.00

Assuming an amortization period of 25 years, the annual rate R is 4 percent of construction cost. Assuming an interest rate of 3.5 percent, average annual interest rate is 1.75 percent.

ROAD CLASS	I	II	III
R	$1,600.00	$ 880.00	$ 600.00
I	700.00	383.00	262.00
M	300.00	400.00	500.00
T	2,500.00	3,000.00	3,500.00
A	$5,100.00	$4,663.00	$4,802.00

Therefore, the Class II is the most economical by a margin of $199.00 less than Class III, and over the period of 25 years the margin in favor of the Class II road is $4,975.00 per mile.

If various segments of a road will serve differing volumes of timber, calculate the annual cost for each segment separately.

312.4 FORMULA FOR ANNUAL VOLUME FOR EQUAL COSTS. Another method of determining the most economical of two standards of roads is to calculate the annual volume "V" in M board feet at which the annual costs of the two roads will be equal. Then if the annual volume will be greater than "V", the higher standard of road will be justified; if lower than "V", the lower standard is indicated. The break-even volume formula is:

$$V = \frac{(R_h + I_h + M_h) = (R_l + I_l + M_l)}{T_l \quad = \quad T_h}$$

Where the subscript "h" indicates the higher standard road and the subscript "l" the lower standard road, T is in $ per M per mile, and the other symbols are those used in Article 312.3.

Example: Using the same costs as in the example in 312.3 for Class II and III roads:

$$V = \frac{(880 + 383 + 400) - (600 + 262 + 500)}{.35 - .30}$$

$$= \frac{1663 - 1362}{.05} = \frac{301}{.05} = 6020 \text{ M board feet}$$

Therefore, for any annual volume exceeding 6,020 M board feet, the Class II road is the more economical, for the cost data used. For any lesser volume the Class III road is the more economical.

If there is a difference in the lengths of two roads, multiply the costs per mile by the number of miles of road for use in the formula.

312.5 TRAFFIC DENSITY. The capacity of a given road may be computed from the following formula:

$$\text{Number of Vehicles per Hour} = \frac{5280 \times \text{Speed in Miles per Hour}}{\text{Interval between Vehicles in Ft.}}$$

For a single-lane road with turnouts the capacity is determined by the average speed of the empty truck which waits at the turnout for the loaded log truck to pass. The minimum interval is the turnout spacing. Application of this formula will show that the capacity of the single-lane road is adequate to handle the volume of log truck traffic plus crew, supervisory, administration and service vehicles, in most situations.

Whether a two-lane road is required is determined by the traffic from public use, i.e., recreationists, miners and farmers. If heavy public use of the road is anticipated, a traffic count on a comparably situated existing road will serve as a guide to the number of vehicles per hour of non-logging traffic. In view of the increasing pressure on forest recreation facilities, it would be well to count on recreation traffic increasing in the future.

312.6 ECONOMIC ANALYSIS FOR CLASS III ROAD GRADIENT. The formulas given in Articles 312.3-312.4 may also be used in making the economic analysis required to justify increasing the gradient of a Class III road above the standard maximum of 10 percent. (Article 312.1) In this case the subscript "h" represents the 10 percent maximum road, and the subsequent "l" the steeper gradient road. If the steeper road will be shorter than the 10 percent road, multiply "R", "I", "M" and "T" per mile by the length of each road in miles before entering in the formulas. The round trip travel time for each of the two gradients may be taken from Table 331-1 or 331-2 or reference (2/). Note the effect of curvature on travel time and costs in Tables 331-3 and 331-4 and adjust "T" where controlled by curvature.

312.7 IMPROVEMENT OF EXISTING ROAD. Where a sub-standard existing road on intermingled private land is to be made a segment of a permanent Bureau of Land Management road, the problem arises of determining the economics of improving the existing road to a higher standard. If time does not permit traversing and leveling to obtain a plan and profile, drive over the road taking odometer and altimeter readings at breaks in grade. Note any curves which reduce speed below that limited by the gradient.

Following is a rapid method of measuring the degree of curve. Lay off a chord of 62 feet by stretching a 100 foot tape along the edge of the road surface with the zero and 62 foot marks, touching the edge of the surface. Measure the middle ordinate in inches from the 31 foot mark to the surface edge. The middle ordinate in inches equals the degree of curve. A folding carpenter's rule is a convenient tool for measuring the middle ordinate. Note other conditions outlined in Article 121.11, "Evaluating an Existing Road." If possible, make a stop-watch time study of log truck travel time over the road. Otherwise draw a rough profile of the existing road from the odometer-altimeter readings and calculate the log truck travel time.

Estimate the cost of improving the existing road to the standard of the road to be built on federal land. Compute the comparative annual costs of using the existing road and the improved road by the formula in Article 312.3.

Another approach is to use the break-even formula in Article 312.4 to determine how much can be expended in improving the road to maintain annual costs at the same level as with the unimproved road. With this expenditure the benefit would accrue to public use rather than to the timber. Any less expenditure would benefit the timber. Set up the break-even formula in the following form:

$$(R_h + I_h) = (R_e + I_e + M_e + VT_e) - (M_h + VT_h)$$

Where the subscript "h" designates the road improved to higher standard and subscript "e" the existing road, R_e is the annual cost of the road purchase. Solve for $(R_h + I_h)$. Then X, the break-even amount which can be expended on an annual cost basis, is found by the formula:

$$X = (R_h + I_h) - (R_e + I_e)$$

Another method of determining how much expenditure is justified to improve the standard of an existing road is to discount future annual savings in trucking and road maintenance to present net worth by the $1.0p^n$ formula familiar to all foresters.

312.8 CONSIDERATION OF OFF-HIGHWAY TRUCKS. The O&C road standards dated June 18, 1959, include the following directive: "Load Limits and Truck Dimensions. Applicable limits to Class I, II and III roads shall be the same as those that govern logging trucks on the public highways of the State of Oregon. Bureau of Land Management State Supervisor's approval is required for deviation from these limits."

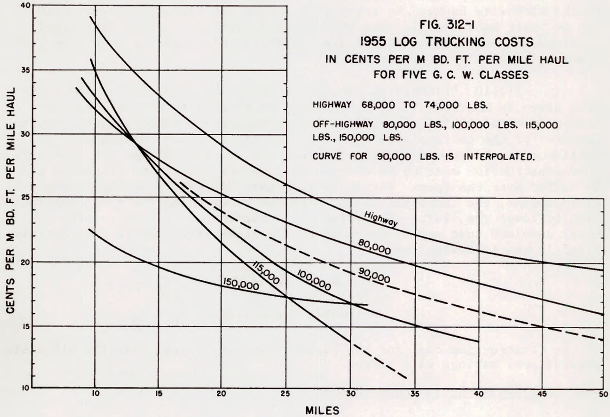
However, if a road terminates at a log dump on water so no haul on state highway or county road is involved, designing the road for off-highway vehicles merits consideration. As a general rule, the larger the gross combination weight class of truck and trailer, the cheaper the cost per M board feet per mile. (Figure 312-1)(7/) The economics of hauling larger loads than are permitted on-highway is covered in reference (3/). Where a large annual volume is to be hauled over an access road, the possible savings in using off-highway trucks on the access road and establishing a reload near the lower terminus for reloading on-highway trucks, should be considered.

Travel time and log trucking cost may be computed from tables in reference (2/). Elements of road construction cost which might increase for off-highway trucks are:

1. Earthwork for wider subgrade.
2. Surfacing rock for wider surface and greater depth to carry

heavier axle loads. (Section 631) The minimum width of surface for two lanes is twice the log bunk width plus 4 feet.

3. Bridges for heavier loading.



312.9 LOOP ROADS. Where the traffic requires a two-lane road but the annual volume of timber to be hauled is insufficient to justify the construction cost, a loop road system of one-way roads may be the best solution. The in-haul road is built to the higher standard desirable for the loaded vehicles. The return road is built to a lower standard for the empty trucks. In some cases an existing low standard road might be used for the return road.

The loop road system is well adapted to the use of off-highway trucks with wide bunks. On steep side slopes two narrower one-way roads can be built more cheaply than the wide two-lane road. Even with legal on-highway trucks the loop road system offers opportunities to reduce truck travel time with greater safety.

312.10 DETERMINING LIMITS FOR TEMPORARY SPUR ROADS. The formulas given in Articles 312.3 - 312.4 may be adapted to determining the most economical limits of gradient and curvature for temporary spur roads. Compute for the contemplated standards the construction, maintenance and hauling costs and compare total combined costs. For "R" use the total road construction cost to be charged off against the volume of timber to be hauled over the spur. For short term use, "I" may be omitted. For a fixed volume, the increased amount that can be expended for road construction to lower the limits of gradient or curvature without increasing the total combined cost may be computed by the break-even formula from Article 312.7 in the following form:

$$R_h + M_h = (R_e + M_e) + V (T_e - T_h)$$

$$\text{Allowable Expenditure} = R_h - M_h$$

If the construction cost for the higher standard is less than the allowable expenditure, savings will accrue.

320 CONSIDERATIONS IN ROUTE SELECTION

320.1 COST. The basic consideration in selecting the route for a road, as in all phases of road engineering, is cost. The cost of initial construction, the cost of future maintenance and the cost of operating vehicles over the road are dependent on the route. In this chapter are given the broader considerations which the road planner should bear in mind in seeking the route which will best serve the purposes for which the road is to be built. Most of the considerations affect costs. By "route" is meant a road line such as is projected on a map or aerial photograph or a reconnaissance or grade line run in the field. It represents a narrow belt of land within which minor variations in gradient or alignment may be made during the preliminary or final location survey. The more detailed considerations for the road engineer to bear in mind in locating the road on the ground after the route has been selected are given in Chapter 330, "Considerations in Road Location." Parts of Chapter 330 are also germane to route selection.

321 SECONDARY ROADS

321.1 THE LOGGING PLAN. The routes of the secondary roads consisting of the spur roads to landings and the lateral or branch roads connecting the spurs with the main road are dictated by the logging plan. Road patterns and road spacing are covered in Chapter 120, "Economic Considerations." It cannot be over-emphasized that the roads and the yarding are interdependent and must be integrated. The logging plan must be feasible for economical road construction and log truck operation. The roads must serve the landings and economical yarding distances. Compromise is often necessary to arrive at the minimum total combined cost of yarding, trucking and roads with due regard to protection and silvicultural considerations. (Chapters 130, 140)

322 MAIN ROADS

322.1 THE SECONDARY ROAD PATTERN. If a main forest road is to be built primarily for hauling logs, then the first consideration in selecting the route of the main road is to serve the secondary branch and spur roads. The main road route should reach suitable junction points where there is room for the branch roads to turn off from the main road. Such junction points include flats, benches, and saddles where there is space for the double width required for grade separation without excessive excavation. If the branch road gradient is steeper than that of the main road, adequate length is required for an easy vertical curve. The junction should be staked and constructed to the point where the branch road subgrade clears the main road at the time the main road is built. The route which will give the minimum combined hauling distance over secondary and main road from the center of gravity of the timber volume will generally be the most economical route.

322.2 THE TOPOGRAPHY. The topography often will determine the selection of the route for a main road. Since the main road usually follows up the main drainage paralleling a sizeable stream, the route possibilities which may be encountered with their relative advantages and disadvantages follow:

1. Wide valley bottom. This condition affords the advantages of a water gradient, good alignment and relatively low earthwork yardage. Good landings are available for settings to be logged along the route. Disadvantages are flood hazard and the cost of bridges to maintain good alignment and to avoid rock cuts if the stream meanders. Protection of recreational resources, such as camping sites and fishing streams, requires special consideration. Stream channel changes are objectionable to fisheries agencies.

2. Narrow valley bottom. This condition offers a water gradient and advantages over a hillside route of less excavation and better alignment, since the mouths of side streams usually can be crossed on tangents with fills. Fewer but larger culverts may be needed. Disadvantages are flood hazards, bridges when it is necessary to cross the stream

to avoid rock cuts or sharp curves, and the difficulty of avoiding interference with the stream channel.

3. Hillside route. Locating a main road on the hillside well away from the creek will eliminate flood hazards and creek damage. Bridges are usually eliminated since side streams can be crossed with fills and culverts. Steeper and more variable gradients are often required. Alignment on the hillside route is poorer since the route following the grade contours around ridges and draws. This also makes the road longer. Excavation is heavier as the side hill is steeper than the valley bottom. Take offs for branch or spur roads are more difficult. Higher cut banks expose more soil to erosion.

4. Ridge crest. A ridge crest route offers the advantages of good alignment, light excavation, good drainage and few culverts. If the ridge profile is uneven, more adverse pitches are encountered, although the possibility of making them momentum grades is good. (Article 331.3) The principal disadvantage is that a main road above the bulk of the timber necessitates adverse grade spurs. A hillside segment of road is required to reach the ridge, and total length of haul may be longer.

322.3 TWO-DIRECTIONAL HAULS. The possibility of the main road being used to haul timber in opposite directions should be considered. The successful bidder on a timber sale may haul up the valley and over the divide to a log market in the opposite drainage. In this case the favorable grade down-valley becomes an adverse grade for up-valley hauls. If the possibility of two-directional hauls exists, all grades should be limited to the allowable adverse grade for the road class.

322.4 EDAPHIC CONSIDERATIONS. Geology and soils are important factors in road construction and maintenance costs. All available geological and soils information along routes under consideration should be collected. An example of the value of geology in route selection is in the angle of the strata in deciding which side of the valley will give the most stability. Cut slopes paralleling the strata will be more subject to slides. The route which encounters more of the granular soils is the preferable route from the standpoint of construction and maintenance. The route which results in the least soil disturbance and which avoids the more erosible soils will minimize erosion and water damage. Slide or slump areas and swamps are to be avoided. Routes through shallow or poorly drained soils will be subject to the hazard of windfalls from the trees along the edges of the road right-of-way clearing. Soils in road design and construction are covered in detail in Division 600, "Soil Engineering."

322.5 MAJOR CONTROL POINTS. The major control points are very important considerations in route selection. Following are possible control points to look for:

1. Terminal Control Points

   a. The beginning of the route, usually the junction with an existing road.

   b. The end of the route. This may be the last point from which spur roads will branch off, the pass at the head of the valley, or a junction with another existing road. Or it may be the end of the current project from which the road can be continued as a later project. The feasibility of the continuation route must be assured.

2. Intermediate Control Points

   a. Saddles or passes in ridges.

   b. Stream crossings where streams narrow, suitable for bridges or fills and culverts.

   c. Benches suitable for branch or spur road junctions or for landings.

   d. Points to safely cross above or below cliffs or rock outcrops, slides and swamps.

   e. Recreational sites such as camping sites, parking sites, and scenic viewpoints.

   f. Crossings of county roads, railroads or farms outside the forest.

322.6 ASPECT. A road along a slope with a southerly aspect will get more sunshine and dry out faster after a rain. Consequently, it will be subject to less damage from traffic and result in lower maintenance cost. Other factors being equal, a route on the north side of an east-west valley is preferable to one on the south side. On a north-south valley, the side which will get the most sunshine is preferred.

322.7 TRUCK PERFORMANCE. The person engaged in the selection of road routes should be cognizant of the effect on truck travel time of gradient and curvature. Tables 331-1 and 331-5 give speeds and round trip travel time for conventional highway trucks. If off-highway trucks or trucks with other horsepower-weight ratios are to be used, their performance can be obtained from the charts in reference (2/).

Among practical points to remember, the following are suggested: Flatten the grade at intervals on a long sustained favorable grade to allow release and cooling of the brakes. Avoid frequent changes of grade on adverse grades which necessitate changing gears with consequent shock to the truck power train. When changing to a steeper grade, reduce the lesser grade 1 or 2 percent for a station to facilitate gear shifting.

In running a tag line or projecting a grade line on a map for the maximum permissible adverse gradient, keep 1 or 2 percent under the maximum to allow for slackening of grade on curves.

322.8 ALTERNATE ROUTES. The best route will seldom be selected if the road planner stops with the first and, to him, most obvious route. Particularly in running reconnaissance lines in the field there is a temptation to give up too easily and accept the first or second trial as "good enough." The high investment in a main road and the years it will be used warrants taking the time to study alternate routes. The planner should be able to substantiate his final selection by comparison with alternate routes he has considered. The comparison should include truck travel time as well as construction cost.

The Bureau of Land Management policy of making a timber sale accessible to more than one market outlet, wherever possible, makes it incumbent on the road planner to consider alternate routes to alternate marketing centers as well as alternate routes to any one market.

322.9 ECONOMIC ANALYSIS OF ALTERNATE ROUTES. The formulas given in Articles 312.4 - 312.5 may also be used for comparison of the annual cost of two or more routes. One common alternative is that of a road with good alignment and truck travel speed but more costly construction than an alternate road with poorer alignment and slower travel speed. Another common alternative is that of a longer route on a gentle favorable grade, as around the point of a ridge, versus a shorter route involving an adverse grade and a steeper favorable grade, as over the ridge.

Example:

1. Longer route segment 3.67 miles of 3 percent favorable grade. Trucking cost 56.2 cents per M board feet. Construction cost $55,050 at 6 percent amortization plus interest = $3,303. Annual maintenance at $300 per mile = $1,101. Total annual cost $4,404.

2. Shorter route segment 2.0 miles at 8 percent favorable, 1 mile at 5 percent adverse. Trucking cost 81 cents per M board feet. Construction cost $41,000 at 6 percent = $2,460. Maintenance at $400 per mile (steeper grades, sharper curves). Total $3,660.

Then the annual volume of haul "V" at which the two routes will be equal in cost is:

$$V = \frac{4,404 - 3,660}{.81 - .562} = \frac{744}{.248} = 3,000 \text{ M board feet}$$

Thus, the longer route will be the more economical if the annual volume hauled exceeds 3 million board feet.

330 CONSIDERATIONS IN ROAD LOCATION

331 TRUCK PERFORMANCE

331.1 TRUCK TRAVEL TIME. The forest road engineer is constantly faced with making decisions as to what degree of curve to locate. He is prone to decide on the basis of what he sees before him--the grade line and the topography--and what he can visualize--the road prism and the earthwork. In his concentration he is apt to forget to consider the effect of his decision on the vehicle which will travel the road. When making a decision on gradient or curvature he should ask himself, "What effect will my decision have on truck travel time?"

To help the forest road engineer to achieve the best balance between gradient and curvature, Tables 331-1 to 331-6 are given. They were derived from formulas and graphs in the 1956 edition of reference(2/).

Table 331-1, "Effect of Gradient on Truck Spped," gives the loaded, empty and average round trip speed in miles per hour and travel time in minutes per round trip mile on favorable and adverse grades for a vehicle of 150 H.P. and 70,000 lb. G.C.W. (Gross Combination Weight of loaded log truck and trailer). Table 331-2 gives the same data for 200 H.P. trucks. Note that the speeds for gradient are on tangents not affected by curves. "Minutes per round trip mile" is the sum of the travel times of the loaded and empty truck on a one mile segment of road.

Table 331-3, "Effect of Curvature on Truck Speed" gives the speed in M.P.H. and the round trip travel time on blind curves on one-lane roads from 3 to 70 degrees of curvature. The same data is given for open curves on one-lane roads and for all curves on two-lane roads from 8.6 to 70 degrees. Note that these speeds are on curves not affected by gradient. A top speed of 40 M.P.H. on gravel-surfaced roads is assumed.

Table 331-4, "Truck Speed Controlled by Curvature," gives for one-lane roads and 10, 15, 20 and 25 curves per mile the average round trip M.P.H. and minutes per mile for average degrees of curvature from 5 to 70 degrees. In using this table average only the curves of degrees greater than one-fourth the largest degree of curve (sharpest curve) in the mile. For example, if the sharpest curve is 60 degrees, average only curves of more than 15 degrees.

Table 331-5 fives the "Gradient on Which Round Trip Speed Equals Speed on Curves," for blind curves from 3 to 75 degrees and open curves from 5 to 75 degrees for 150 H.P. 70,000 lb. G.C.W. vehicles. Table 331-6 gives similar data for 200 H.P. 70,000 lb. G.C.W. vehicles.

The road locator should also note the practical points mentioned in Article 322.7 with regard to slackening gradient for gear shifting. To avoid gear shifting on curves on adverse grades, to overcome curve resistance, reduction in gradient of 0.04 percent per degree of curve is recommended. For example, reduce the gradient on a 25 degree curve by (25 x 0.04) or 1 percent, on a 50 degree curve by 2 percent, on a 75 degree curve by 3 percent.

EFFECT OF GRADIENT ON TRUCK SPEED
Gravel Surface

TABLE 331-1

150 HP 70,000 lb. G.C.W.

Grade %	Loaded MPH	Empty MPH	Per Round Trip Mile Average MPH	Per Round Trip Mile Minutes
	Adverse	Down		
10	4.8	18.5	7.6	15.75
8	5.8	21.8	9.2	13.10
6	7.3	26.7	11.5	10.50
4	9.8	34.3	15.2	7.90
3	11.7	40.0	18.1	6.60
2	14.5	40.0	21.3	5.60
1	19.0	40.0	25.8	4.65
0	27.9	40.0	32.9	3.65
	Favorable	Up		
1	33.3	40.0	36.3	3.30
2	40.0	37.5	38.7	3.10
3	40.0	33.0	36.2	3.30
4	34.3	28.6	31.2	3.85
6	26.7	22.6	24.5	4.90
8	21.8	18.5	20.0	6.00
10	18.5	15.6	16.9	7.10
12	16.0	13.5	14.6	8.20
14	14.1	11.8	12.8	9.30
16	12.3	10.5	11.3	10.60
18	10.6	9.6	10.0	12.00

TABLE 331-2

200 HP 70,000 lb. G.C.W.

Grade %	Loaded MPH	Empty MPH	Per Round Trip Mile Average MPH	Per Round Trip Mile Minutes
	Adverse	Down		
10	6.3	18.5	9.4	12.70
8	7.6	21.8	10.7	10.60
6	9.4	26.7	13.9	8.60
4	12.9	34.3	18.7	6.40
3	15.6	40.0	22.5	5.35
2	19.0	40.0	25.7	4.65
1	24.4	40.0	30.0	3.95
0	33.3	40.0	36.3	3.30
	Favorable	Up		
1	40.0	40.0	40.0	3.00
2	40.0	40.0	40.0	3.00
3	40.0	40.0	40.0	3.00
4	34.3	40.0	36.8	3.25
6	26.7	40.0	32.1	3.75
8	21.8	34.2	26.6	4.50
10	18.5	30.0	22.9	5.25
12	16.0	26.4	20.0	6.00
14	14.1	23.0	17.6	6.80
16	12.3	20.7	15.4	7.80
18	10.6	18.7	13.5	8.90

TABLE 331-3 - EFFECT OF CURVATURE ON TRUCK SPEED

Safe Speed on Blind Curve 1-Lane Road

Degree Curve	Per Round Trip Mile Speed	Per Round Trip Mile Minutes
0.0	40.0	3.0
3.0	34.0	3.5
5.0	28.6	4.2
10.0	22.2	5.4
15.0	18.7	6.4
20.0	16.0	7.5
25.0	14.7	8.2
30.0	13.8	8.7
40.0	12.1	9.9
50.0	11.5	10.5
60.0	10.8	11.1
70.0	10.2	11.7

Safe Speed on Open Curve 1-Lane Road - All Curves 2-Lane Road

Degree Curve	Per Round Trip Mile Speed	Per Round Trip Mile Minutes
8.6	40.0	3.0
10.0	37.0	3.2
15.0	28.3	4.2
20.0	26.2	4.6
25.0	23.4	5.2
30.0	21.4	5.6
40.0	18.4	6.5
50.0	16.4	7.2
60.0	15.1	7.9
70.0	14.0	8.6

TABLE 331-4

TRUCK SPEED CONTROLLED BY CURVATURE

Average Degree Curve	10 Curves Per Mile		15 Curves Per Mile		20 Curves Per Mile		25 Curves Per Mile	
	Ave. MPH	Minutes	Ave. MPH	Minutes	Ave. MPH	Minutes	Ave. MPH	Minutes
5	32.0	3.7	30.8	3.9	30.5	3.9	30.1	4.0
10	23.8	5.0	22.4	5.3	22.0	5.4	21.6	5.6
15	19.9	6.0	18.5	6.5	17.8	6.7	17.3	6.9
20	19.1	6.3	17.7	6.8	16.9	7.1	16.4	7.3
25	18.1	6.6	16.4	7.3	15.6	7.7	15.0	8.0
30	17.1	7.0	15.4	7.8	14.5	8.3	13.9	8.7
40	15.9	7.5	14.0	8.5	13.0	9.2	12.6	9.5
50	15.2	7.9	13.4	9.0	12.3	9.8	11.5	10.5
60	14.7	8.2	12.7	9.4	11.7	10.3	10.9	11.0
70	14.3	8.4	12.5	9.6	11.2	10.7	10.3	11.6

TABLE 331-5

GRADIENT ON WHICH ROUND TRIP SPEED EQUALS SPEED ON CURVE
150 HP 70,000 lb. G.C.W.

Blind Curve Degree	Favorable Grade %	Adverse Grade %	Open Curve Degree	Favorable Grade %	Adverse Grade %
3	3.25				
5	4.70	0.60	5	1.30	
10	6.95	1.80	10	2.45	
15	8.70	2.80	15	4.80	0.65
20	10.80	3.70	20	5.45	0.95
25	12.00	4.20	25	6.45	1.55
30	12.95	4.70	30	7.30	2.00
35	14.00	5.20	35	8.10	2.50
40	15.00	5.65	40	8.95	2.90
45	15.40	5.90	45	9.60	3.20
50	15.80	6.10	50	10.25	3.50
55	16.40	6.40	55	10.90	3.80
60	17.00	6.60	60	11.60	4.00
65	17.40	6.80	65	12.20	4.30
70	17.80	7.00	70	12.70	4.60
75	18.20	7.20	75	13.20	4.90

TABLE 331-6

GRADIENT ON WHICH ROUND TRIP SPEED EQUALS SPEED ON CURVE
200 HP 70,000 lb. G.C.W.

Blind Curve Degree	Favorable Grade %	Adverse Grade %	Open Curve Degree	Favorable Grade %	Adverse Grade %
3	5.7	0.6			
5	7.1	1.3	5		
10	10.5	3.1	10	3.9	
15	13.0	4.0	15	7.2	1.4
20	15.5	5.1	20	8.3	2.0
25	16.8	5.7	25	9.7	2.7
30	17.6	6.1	30	11.0	3.4
35	18.6	6.5	35	12.1	3.7
40	19.7	6.9	40	13.3	4.1
45		7.2	45	14.1	4.4
50		7.5	50	14.9	4.8
55		8.0	55	15.6	5.1
60		8.4	60	16.4	5.5
65		8.6	65	16.9	5.7
70		8.8	70	17.5	6.0
75		9.0	75	17.8	6.2

331.2 LOG TRUCKING COST. Log trucking costs for economic analysis of roads may readily be obtained by applying the current machine rate to the "minutes per round trip mile," for the relevant conditions, in Tables 331-1 to 331-6. The applicable machine rate is the current cost of owning and operating a log truck and trailer for one minute, excluding tire cost. Tire cost is computed on a mileage basis. The machine rate is composed of the following cost elements:

Current operating cost, including labor, fuel, lubricants, maintenance and repairs.

Ownership cost, including depreciation, interest, taxes and insurance.

Then "minutes per round trip mile" multiplied by machine rate per minute, plus tire cost for two miles, gives hauling cost in dollars per mile of haul. This cost divided by the average log load gives the unit cost in cents per M board feet per haul mile.

Example: Given 15 curves per mile, average curve 30 degrees, percent favorable grade. In Table 331-1 read 7.1 minutes per round trip mile for 10 percent grade. In Table 331-4 read 7.8 minutes per round trip mile for 15 curves per mile averaging 30 degrees. Therefore, travel time is controlled by curvature. If current machine rate for 150 HP log truck and trailer is 20 cents per minute, and tire cost is 20 cents per mile, or 40 cents per round trip mile, then cost per mile haul = 7.8 minutes X $0.20 per minute = $1.56 plus $0.40 tire cost = $1.96 per mile. If average load is 6 M board feet, then $1.96 divided by 6 = 32.7 cents per M board feet per haul mile.

331.3 MOMENTUM GRADES. The use of "momentum" or "velocity" adverse grades offer opportunity to decrease curvature or length of road with consequent savings in construction cost and travel time. The momentum of the vehicle at the bottom of the grade is utilized to help overcome grade resistance. The approach to the momentum grade and the grade itself should be on a tangent so that speed is not restricted by curvature. Momentum grades are adapted to ridge-crest routes and to crossing draws on tangent to avoid curving into and out of the draw on a grade contour, thus eliminating three curves. Following is a formula for computing the length of a momentum grade:

$$\text{Distance} = \frac{\text{Initial Momentum - Final Momentum}}{\text{(Grade + Rolling Resistance) (GCW)-(Net Tractive Effort)}}$$

$$\text{Net Tractive Effort} = \frac{\text{Torque x Total Gear Reduction x .72}}{\text{Tire rolling radius in feet}}$$

For example, given a 200 HP, 70,000 lb. GCW truck, 584 ft. lb. torque at 1800 RPM, tire rolling radius 1.6 ft. Total Gear Reduction in direct drive 8.1. Rolling resistance, compacted gravel, equivalent to 1.8 percent grade.

$$\text{Net Tractive Effort} = \frac{584 \times 8 \times .72 = 2100 \text{ lbs.}}{1.6}$$

Assume that an 8 percent momentum (adverse) grade is approached by a 6 percent favorable grade on which the speed will be 26.7 MPH or 39.2 feet per second. What distance will the truck travel up the 8 percent grade in direct drive before the speed slows to the speed on an 8% adverse grade of 7.6 MPH or 11.1 feet per second?

$$\text{(Grade + Rolling Resistance) (GCW)} = (.08 + .018)\ (70000) = 6860 \text{ lbs.}$$

$$\text{Momentum} = \frac{\text{(GCW) (Velocity ft. per sec.}^2)}{64.4}$$

$$\text{Initial Momentum} = \frac{(70{,}000)(39.2^2)}{64.4} = 1{,}670{,}210 \text{ ft. lb.}$$

$$\text{Final Momentum} = \frac{(70{,}000)(11.1^2)}{64.4} = 133{,}920 \text{ ft. lb.}$$

$$\text{Distance} = \frac{1{,}o70{,}210 = 133{,}920}{6860 = 2100} = \frac{1{,}536{,}290}{4760} = 323 \text{ feet}$$

Thus any distance less than 323 feet on the 8 percent momentum grade can be made in direct drive without shifting gears. The difference in elevation is 323 x .08 or 25.8 feet. Any momentum grade with a difference in elevation of 25.8 feet would have the same effect. For example on a

10 percent grade the momentum distance would be 258 feet; on a 6 percent grade 430 feet. If a shift were made to a lower gear with greater gear reduction and net tractive effort a longer momentum grade could be used. In the above example the distance the truck would coast up without power until the speed dropped to 7.6 MPH would be: $\frac{1,536,290}{6,860}$ or 224 feet.

332 CONSTRUCTION METHODS

332.1 CONSTRUCTION MACHINERY AVAILABLE. The construction method which will be used is an important economic consideration in road location. A timber sale road to be built by a logging operator, whose only grading equipment is a bulldozer, requires different design than an access road to be built by a contractor equipped with scrapers and power shovels as well as bulldozers. Table 332-1 gives a comparison of production and costs of excavation and haul.

Economy in grading with the bulldozer will be achieved if the road is so designed that:

1. Earth is side cast and wasted rather than end hauled.
2. End hauls are kept short. (Table 332-2)
3. Earth is moved down-grade with the aid of gravity, not up.
4. Fill material is borrowed rather than hauled farther than economic limit of bulldozer haul.
5. Cuts in rock requiring blasting before bulldozing are minimized.
6. Soft or swampy ground and blue clay is avoided.

The advantages of balanced sections in reducing soil disturbance and exposure to erosion should be weighed against the increased cost of grading balanced sections of excavation and embankment with a bulldozer.

In designing for power shovel excavation:

1. Rock cuts can be heavier in rock which the power shovel can excavate without blasting.
2. Long end hauls are economical with power shovel and dump trucks.
3. Therefore, balanced sections can be used.
4. The power shovel can work on mats in soft or swampy ground where a bulldozer could not operate.

In designing for scraper grading:

1. Balanced sections are economical.

2. End hauls up to 1,000 feet can be planned. This is the customary free haul distance in road construction contracts.

3. Rock and swamp is to be avoided.

TABLE 332-1

COMPARATIVE PRODUCTION AND COSTS PER HOUR
CLAY SOIL, BANK CUBIC YARDS, 50 MINUTE HOUR

Haul Feet	Bulldozer (185 HP)		Scraper (7-9 Cu. Yd.)	
	Output Cu. Yd.	Cents per Cu. Yd.	Output Cu. Yd.	Cents per Cu. Yd.
50	240	5.6		
100	130	10.3		
150	100	13.4		
200	75	17.8		
250	60	22.3		
300	50	26.8		
350	40	33.5	112	12.4
400	30	44.8	107	13.1
600			90	15.5
800			78	17.9
1000			68	20.6

POWER SHOVEL

Size Cu. Yd.	Output in Cu. Yd. Digging			Cents per Cu. Yd. Digging		
	Easy	Medium	Hard	Easy	Medium	Hard
3/4	125	84	60	9.2	13.7	19.2
1	168	112	80	8.9	13.3	18.6
1½	238	160	110	8.3	12.3	17.9

Dump truck haul, 30 cents per cu. yd. first mile.

TABLE 332-2

BULLDOZER EARTH MOVING PRODUCTION IN PERCENTAGE OF PRODUCTION ON 10% FAVORABLE GRADE FOR 100 FT. HAUL

Horizontal lines indicate approximate economic limit of haul for various grades.

Haul Feet	Adverse Grade %		Level	Favorable Grade %			
	10	5	0	5	10	15	20
50	54	72	90	126	161	198	234
75	43						
100	33	44	56	76	100	122	144
125			47				
150			38	54	70	86	102
200				42	54	65	77
250				33	43	52	62
300					35	43	51
350						36	43

332.2 CONSTRUCTION COST FACTORS. The construction cost factor over which the road engineer exercises the most control, through location and design, is earthwork yardage. Any increase in depth of cut or height of fill at center line increases the yardage of earthwork and the clearing and grubbing acreage, with consequent increase in costs. Culvert length increases with increase in fill height. In fitting a grade line to a profile at a class III road, Calders' Table 18 is a useful guide to the effect on yardage of raising or lowering the grade line. (4/) Actual yardage will be greater, since Calders' Table 18 is for a half-base in excavation of 11 feet, whereas the corresponding half-base of a class III road is 10 feet plus (3 x surfacing depth in feet). Calders' Table 17 is helpful in finding the cut on steep side slopes to obtain the desired width of subgrade on solid ground.

Where surfacing rock is scarce and surfacing costs high, saving in length of road, even at an increase in earthwork, is desirable.

Whether rock can be ripped is an important cost factor. Rock which can be ripped with a tractor-drawn ripper can be excavated at much lower cost than rock which requires blasting. The use of the Reflecting Seismograph makes it possible to determine whether rock is rippable, as well as measuring the thickness of the overburden and the thickness of rock layers of differing densities down to the top of the hardest layer. The instrument is also useful for finding depth to bed rock for bridge pier foundations. The development of tractors of 335 horsepower has greatly extended the range of rippable rock. (8/)

332.3 ECONOMIC MAXIMUM DEGREE OF CURVE. The road engineer is frequently faced with making a decision on the degree of curve to locate around sharp ridges where a large central angle is involved. Table 332-1 gives factors for determining the maximum degree of curve, based on savings in trucking cost compensating for increase in construction cost, for various side slopes. The central angle divided by the factor equals the degree of curve. Side slope percent is measured at the mid-point. Factors are given under column headings at million board feet per annum to be hauled the first line being for a blind curve and the second line for an open curve. The table is derived from a study by Nelson. (5/)

Excavation yardages are based on common up to 35 percent side slope 50 percent rock on 50 percent side slope, and 100 percent rock on 70 percent and steeper side slopes. Unit costs are 40 cents per cubic yard for common and $1.20 per cubic yard for rock. Annual amortization rate is 4.5 percent: truck machine rate is 46.8 cents per minute for a 6 M board feet payload. Since the annual haul required to pay for construction is equal to amortized construction cost divided by the saving in hauling cost, annual volume for any other unit costs is proportional. For example, its excavation rates are 20 and 60 cents per cubic yard, or one-half the rates used in compiling the table, trucking rate unchanged, annual volume for a given factor will be one-half the volume shown in the column heading.

TABLE 332-2

FACTORS FOR DETERMINING DEGREE OF CURVE BASED ON SAVINGS IN TRUCKING COST COMPENSATING FOR INCREASE IN CONSTRUCTION COST

	Million Board Feet per Annum						
Blind Curve:	1	2	3	5	10	20	30
Open Curve:	1.5	3	4.5	7.5	15	30	45
Side Slope %							
10	2.42	3.10	4.16	5.00	6.67	5.94	
20	1.65	2.14	2.94	3.58	4.63	5.94	
30	1.21	1.61	2.16	2.65	3.49	4.51	5.33
40	0.89	1.21	1.60	2.03	2.73	3.52	4.17
50	0.70	0.96	1.23	1.60	2.20	2.84	3.51
60	0.57	0.79	1.00	1.31	1.83	2.41	2.87
70	0.45	0.64	0.84	1.10	1.54	2.10	2.55
80	0.39	0.54	0.71	0.93	1.33	1.89	2.29
90	0.35	0.46	0.63	0.81	1.17	1.73	2.09
100	0.33	0.41	0.60	0.73	1.04	1.64	1.93

$$\text{Degree of Curve} = \frac{\text{Central Angle}}{\text{factor}}$$

Example: If side slope is 50 percent, annual haul 5 million bd. ft., for a blind curve, the factor is 1.60. If the central angle I is 90° then the maximum degree of curve = 90 / 1.60 = 56°. For an open curve interpolating in the table, f = 1.29 and degree of curve = 90 / 1.29 = 70°.

333 SOIL AND WATER RESOURCE PROTECTION

333.1 DRAINAGE AND EROSION CONTROL. As provisions for drainage and erosion control are carried out during design and construction, they are covered in detail under divisions 700 "Road Design" and 800 "Construction Engineering." However, they are mentioned here as a reminder that much can be done to minimize drainage and erosion problems in the location of the road. The location which results in the least soil disturbance, with the lightest cuts and fills, is the best location from the standpoint of erosion control, as well as grading cost. Breaks in long sustained grades, to permit ditch water to be carried by a cross drain to the lower side of the road, will help drainage as well as truck performance. Streams and draws should be crossed at the best sites for culverts. Switchbacks and their approaches create drainage problems as well as trucking problems. Avoiding slide, slump, sheet erosion, poorly drained, and other such problem areas in location will avoid construction and maintenance problems, and erosion due to them.

Locating a road on the lowest possible gradients will reduce maintenance cost as well as trucking cost. The erosive effect of water increases with increase in gradient. Road surfacing wear from tire action depends upon truck speed. The relation between road gradient and water action, tire action and the two combined is shown in the following tables by Nelson. (6/) Data are expressed as the ratio to action on a 6 percent grade.

Road Grade Percent	Water Action Ratio	Tire Action Ratio	Combined Action Ratio
0	0.06	2.26	1.00
2	0.13	2.26	1.04
4	0.45	1.61	0.95
6	1.00	1.00	1.00
8	1.91	0.67	1.38
10	3.20	0.48	2.03
12	4.92	0.36	3.05
14	7.09	0.28	4.16
16	9.65	0.22	5.59
18	17.73	0.18	7.33

333.2 RECREATIONAL CONSIDERATIONS. Locating a road through potential recreation areas requires special consideration of the protection of recreational values. These include camp sites, fishing streams, and scenery. The safety of the traveling public is also a consideration. Since the sight of logging slash or slash burns is objectionable to recreationists, screening is desirable. In locating a road through a recreational area the following measures are recommended:

1. Locate the road well back from the main stream to avoid interference with the stream channel or siltation of the water.

2. Preserve camp ground sites by following the contour around the foot of the slope, instead of crossing the flat.

3. Provide ample turnouts and access to parking spaces.

4. Leave a fringe of timber between the road and the stream, if this can be done without creating a windthrow hazard. Provide for felling all danger trees.

5. Locate landings on spurs off of the main road. A spur to a landing should leave the main road on a curve, so the traveling public cannot see the logging slash.

6. Leave a scenic belt of timber between the road and the clear-cut setting boundary.

7. Minimize cuts and fills and resulting scars.

8. Locate gravel pits and borrow pits out of sight of the road so far as possible.

9. On a ridge crest or hillside road which will be used by the public, flatten the gradient at scenic vista points and provide ample turnout and parking space.

The relative weight to be given to recreational considerations as opposed to economic and other considerations is a matter of administrative policy decision.

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CONTENTS

400 ROUTE PROJECTION AND RECONNAISSANCE

410 ROUTE PROJECTION

411 ROUTE PROJECTION ON LARGE SCALE MAPS

411.1 INTRODUCTION. "Route projection" is the laying out of a route for a road on a topographic map or aerial photo. The route defines the narrow strip of land within which the field preliminary survey is made. "Large scale maps" are the 400 feet to the inch, 20 feet contour interval maps made by the Cartographic Section, Oregon State Office, Bureau of Land Management, or maps made by the method given in Chapter 220. Route projection on small scale maps, such as enlargements of U.S.G.S. quadrangles, is similar but less detailed.

Prior to starting the route projection, ascertain the proposed standard of the road. Assemble other pertinent basic data listed in Section 211, any logging plans which have been made, and soil or geological maps of the area served by the road. For economic analysis, collect data on timber volumes, annual cut, and road construction and log trucking costs. Obtain the aerial photos covering the routes for study for tone indications of granular soil and poorly-drained ground.

Review of Chapter 320 "Considerations in Route Selection," and Chapter 330 "Considerations in Road Location" before starting the route projection is recommended. The consecutive steps to follow in making a route projection are given in ensuing Articles 411.2 to 411.5. This procedure is also followed in paper location on strip topography (Section 522).

411.2 SELECTING CONTROL POINTS.

1. Determine the terminal control points: where to begin from an existing road or location survey, and where to end the present project. If the road may be extended in the future, the upper terminal should be at a point suitable for continuing the road. This may necessitate projecting the road beyond the present project, to insure that it does not "dead end." The lower terminal is usually the more flexible, and subject to change when intermediate control points are found, and the grade contour projected.

2. Look for major control points between the terminals. Possible control points are listed in Article 322.5. These are usually saddles or passes, benches for spur road junctions, and suitable crossings of large streams, where bridges or large plate culverts are required. If a logging plan is involved, landings along the road route may be control points. If projecting a main road from which stub spurs to landings will take off, suitable junction points for the spurs are controls. Work from the top down, as the valleys and control points tend to constrict at the higher elevations and to widen out at the lower elevations.

3. Look for minor control points along the probable route between major control points. These include points at which obstacles can be passed, such as above or below cliffs, rock outcrop or slides, and either side of the swamps. Mark these points with a red pencil for "danger". Look for evidence of soft or poorly drained ground, and the best places to cross or avoid them, and for the best crossings of side streams. Mark these with blue pencil for "water".

4. Where the route will follow a water grade along a main creek, study both sides of the valley to determine whether to project alternate routes paralleling the creek on each side of the valley, or, in the case of a meandering stream or a valley with cliffs or steep side slopes alternating from one side to the other, to project a route which would cross the creek at intervals. It may be necessary to project all three alternate routes and compare costs to determine the preferable route.

411.3 PLOTTING GRADE CONTOUR.

1. The next step is to plot a grade contour between control points. A grade contour is the line which follows the ground surface at the uniform grade between two control points. The grade contour is drawn as a guide to the projected route. Measure the approximate distance between control points. If the line is not reasonably straight, step off the distance with dividers or measure with a Hamilton map measurer. Interpolate the control point elevations, and compute the grade between them. Set dividers at the distance for one contour interval at this grade.

Example: Difference in elevation between control points 160 feet. Distance 2,000 feet, grade 8%. Set dividers at 20/.08 = 250 feet for 20 feet contour interval.

Starting at one control point, step off successive contours with the dividers. If the trial grade contour does not hit the elevation of the other control point, recompute distance and grade, re-set dividers and step off a second trial line.

2. When the required grade has been found, set pencil drawing compass at the correct distance for one contour interval. Step off the grade contour line, ticking each contour crossed on the map with the pencil point. In going around sharp ridges or narrow valleys, take care not to exceed the maximum degree of curve for the standard of road. Make a plastic curve templet with a radius at map scale equal to the radius of the maximum curve. Lay it on the map and step off around it with the compass. Keep track of the distance and compute the contour which the grade will hit at the estimated end of the curve.

If the topography is broken, or the grade percent low, it is preferable to set the compass at one-half the grade distance for one contour interval and mark every other tick half-way between the contour lines.

411.4 PLAN PROJECTION. Draw a plan of the road following the grade contour as a guide. In plan view a road consists of a series of straight lines, "tangents," connected by curves. The curves are geometrically tangent to the straight lines, the radii being perpendicular at the beginning and ends of the curves. With a transparent drafting triangle, draw a series of tangents through two or more tick marks which are in line. Fit curves to the tangents by trial. Curve fitting is facilitated by using a transparent plastic curve templet with curves at 5° or 10° intervals, to the scale of the map. Recommended templet design is shown in Figure 411-3.

411.5 TRIAL PROFILE. A profile is desirable as a check on the gradients as well as to indicate where heavy earthwork is involved, for use in construction cost estimating and locating culverts. Set the dividers at a convenient distance to map scale, as one-half inch or two stations for 400 feet to the inch scale, and step off along the projection line. Read off and tabulate the station and elevation at each divider point. Elevations can be easily interpolated to ¼ contour, or 5 feet on the 200 foot contour interval map. Number every 5th divider point, or every 10 stations. Plot the profile on profile paper. A convenient scale is 1 inch = 400 feet horizontal scale and 1 inch = 40 feet vertical scale. Plot the grade line on the profile.

If the grade between any two control points exceeds the allowable maximum, due to the projection line being shorter than the grade contour, revise the projection to increase the length, if possible. Plot a trial profile of the revision, and check the grade line. If it is not possible to develop sufficient length of road to keep within the maximum grade limit, then new control points and a new route must be found. Plot the trial profile for the most critical segments first. This may obviate waste of time in plotting other sections which have to be abandoned if the critical section proves to be unusable.

411.6 COST COMPARISON OF ALTERNATE ROUTES. If alternate routes are projected, a comparative cost estimate is made to determine the most economical route.

1. Construction cost estimate. Divide the road plan into sections of uniform side slopes to the nearest 10 percent. Scale the distance between contours adjacent to the projection line at sample points and divide into the difference in elevation to obtain slope percent. Estimate clearing and grubbing and grading costs. Figures 5 and 6, reference(2/), Division 300 are useful for estimating quantities. Estimate the culverts needed and culvert costs. If sections of heavy grading are involved, such as deep cuts through ridges, or high fills, a rough estimate of the earthwork can be made by reading off cuts or fills from the trial profile, scaling side slopes, and

obtaining cubic yards per 50 feet from Calders' Tables 18 or 19. For cuts exceeding 13 feet or fills exceeding 5 feet, the limit of the tables, sketch cross sections and compute volumes. The costs of temporary bridges may be estimated from local experience. Cost estimates on permanent bridges should be obtained from the state office, since they will usually be designed by Bureau of Public Roads bridge engineers. The relative availability of surfacing rock may be an important cost consideration.

2. Transportation cost estimate. Comparative truck travel tires may be found from the tables given in Section 331. Log trucking costs may be computed by using cost data in reference(2/) Division 300.

3. Maintenance cost estimate. No comparison of alternate routes is complete without considering maintenance costs. A road which is cheaper in initial construction cost may be the more costly over a period of years, when maintenance is included. As maintenance costs vary with surfacing material and traffic, as well as gradient and curvature, local experience is the best guide to maintenance cost estimating.

4. A comparison of the totals of construction, maintenance, and trucking costs weighted by the volume of timber to be hauled over the road will indicate the economical route. Other factors such as recreational use may determine the preferable route.

411.7 FINAL CHECK. Transfer the projected route to the road key map or overall transportation plan map. Note whether the route fits in with the overall road system for the area. All work on maps and photos should be cross-referenced with field notebooks of reconnaissance and survey. All field books should be indexed as the work progresses.

412 ROUTE PROJECTION ON AERIAL PHOTOS

412.1 INTRODUCTION. In the open pine forests, road routes may be satisfactorily projected on aerial photos. In dense Douglas-fir forests, routes cannot be projected in as much detail. However, photo-projection may eliminate unfeasible routes and reduce the time spent in field reconnaissance.

The consecutive steps in route projection are similar to those given in Section 411. Visible control points are located. The difference in elevation between each two control points are determined. The horizontal distances between the control points are measured. The average gradients between control points are computed. In dense forest cover, some control points may not be visible, and must be found by reconnaissance in the field. Control points which are usually visible on aerial photos are the terminals, saddles, benches, and crossings of the larger

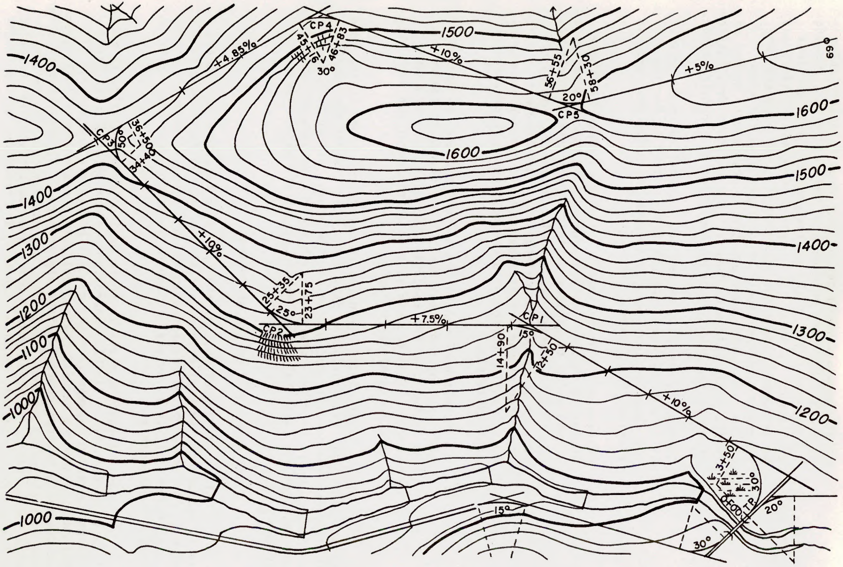


FIGURE 411-1 Plan of Projected Roads
Scale 1" - 400' C.I. 20'

FIGURE 411-2 Profile of Projected Road. Class III

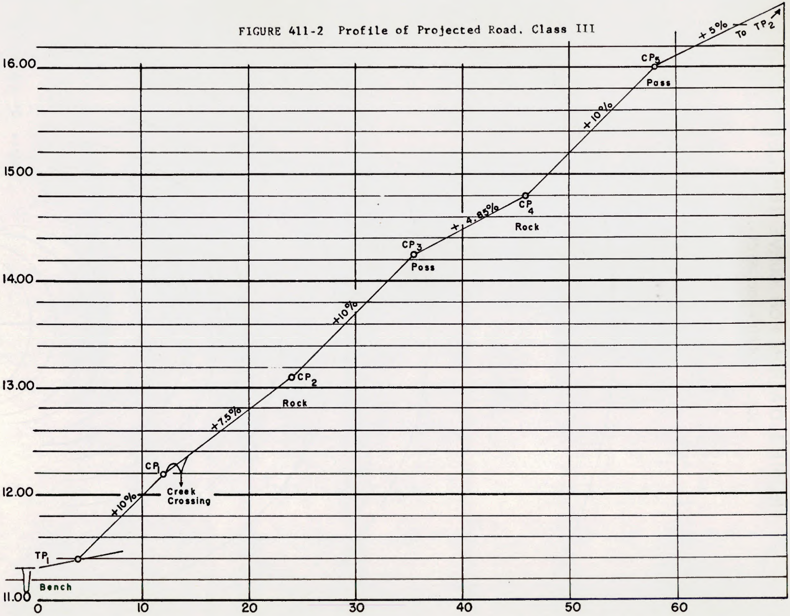


FIG. 411-3 DIAGRAM FOR CURVE TEMPLET

SCALE 1 INCH = 100 FEET

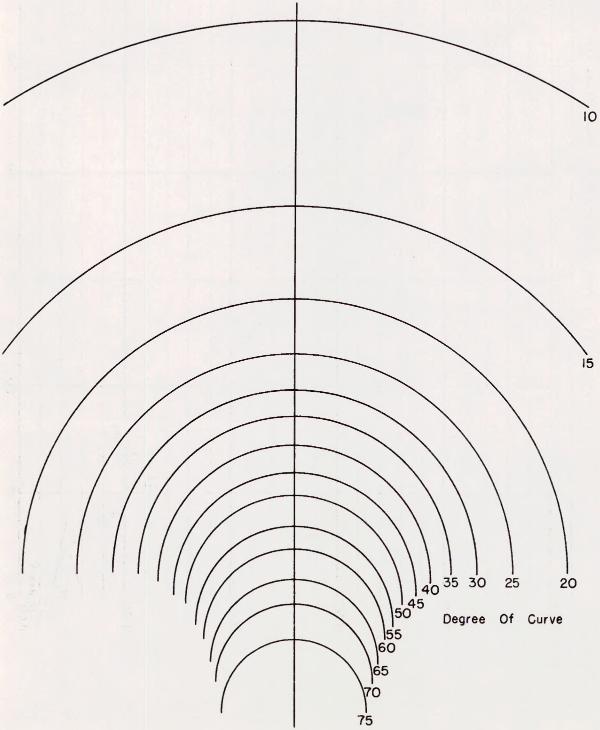
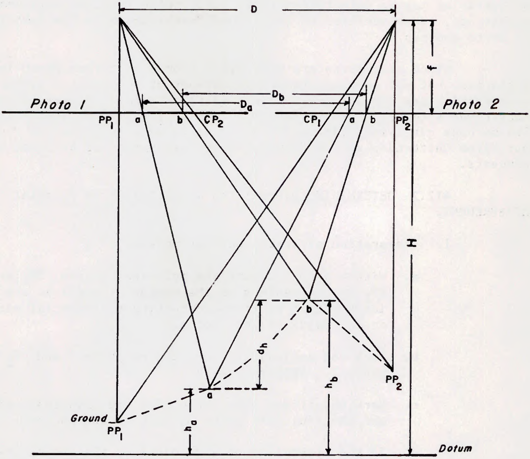
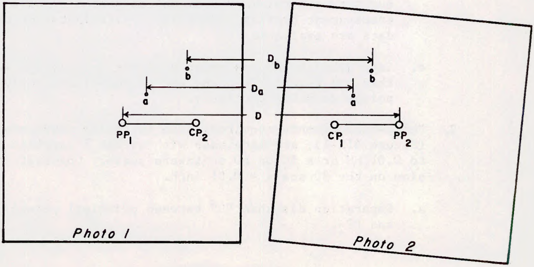


FIGURE 412-1

DIFFERENCE IN ELEVATION BY PARALLAX MEASUREMENT THEORY





streams in the open. Crossings of smaller streams are often obscured by the trees. Rock outcrops and slides may be visible or hidden. Where forest cover obscures the ground, it is necessary to know the a average height of the trees in order to obtain ground elevations. The experienced photo-interpreter can detect swamps and poorly-drained soils which should be avoided. Gravel deposits suitable for embankment or surfacing may be detected by their light color tone and well-drained appearance. When verified on the ground, mark them with the symbol ⚒ on photo and map.

Since most foresters have had a course in forest photo-interpretation, but not in photogrammetry, methods of determining differences in elevation are given in detail in ensuing articles. To make parallax measurements requires skill, but skill can be acquired with practice. The methods given in Articles 412.2 and 412.3 were developed by Professor Hiram Chittenden at the University of Washington and are used by students.

412.2 DETERMINING DIFFERENCES IN ELEVATION BY PARALLAX MEASUREMENT.

1. Preparation of stereo pair of photos.

   a. With a drop pen mark the principal points, PP_1 and PP_2 on the centers of the photos, 1 and 2 at the intersection of lines connecting the fiducial marks on the edges of the photos.

   b. Mark the conjugate points CP_2 on photo 1 and CP_1 on photo 2. (Figure 412-1)

   c. Mark the flight line connecting the principal point and the conjugate point on each of the photos.

   d. If the elevations of any points on the photos are known, or any distances between two points, as along existing roads or between pin-pointed section or quarter corners, mark them on the photos or on a transparent overlay. Note any tree heights for which data are available.

   e. Tape down the photos under a mirror stereoscope so that the flight lines and the principal and conjugate points coincide precisely.

2. Photo-measurements required. The following measurements (Figure 412-1), are made made with either a parallax bar to 0.01 MM or a 50 or 60 engineers scale. One-half division on the 50 scale = 0.01 inch.

   a. Separation distance "D" between principal points PP_1 and PP_2.

b. Distance "Da", measured parallel to the flight line between the images of one of the two control points, the elevation of which is known or assumed.

c. Distance "Db", measured parallel to the flight line between the images of the other of the two control points. Control points "A" and "b" must appear in the common overlap of the stereo pair.

3. Computation of flight altitude. To compute difference in elevation between two points by the parallax measurement method, "H", the flight altitude above datum (usually sea level) and "ha" the elevation above datum of point "a", are required. Flight altitude may be calculated from a known distance and elevations on the photos. The terminal photos of each flight made for the Bureau of Land Management show the average scale R.F. for the flight and the focal length "f" of the lens. Flight height above the ground = flight altitude - ground elevation = (H-h), then $R.F. = \dfrac{f}{(H-h)}$

The Bureau of Land Management photos are usually 1 : 12,000 scale taken with 12 inch lens, or 1 : 15,840 scale taken with 8¼ inch lens. The latter scale is preferable for road projection due to greater relief displacement. Then average flight height is

$$\frac{1}{15840} = \frac{0.6875'}{(H-h)} \qquad (H-h) = 10,890$$

Flight altitude H = (H-h) + h. If the average ground elevation was, say, 500 ft., it would be 10,890 + 500 = 11,390 ft.

Since the photo scale varies with the elevation, it is desirable to calculate H for the stereo-pair of photos from a known distance and elevation.

$$R.F. = \frac{\text{Photo distance}}{\text{ground distance}}$$

$$\text{Average elevation } h = \frac{h_a + h_b}{2}$$

$$(H-h) = \frac{f}{R.F.}$$

Example: Distance between A and b 1762 feet or 21,144 inches. Photo distance a to b = 1.524 inch. Elevations: h_a 395, h_b 536 average 465 feet. f = 8¼ inches = 0.6875 feet.

$$R.F. = \frac{1.524}{21,144} = \frac{1}{13,870}$$

$$(H-h) = \frac{f}{R.F.} = (0.6875)\ (13870) \quad 9535 \text{ ft.}$$

$$H = 9535 + 465 = 10,000 \text{ ft.}$$

4. Computation of difference in elevation. The parallax equation for dh, the difference in elevation between two points "a" and "b"

$$dh = \frac{(H-h^a) \quad (Da - D^b)}{D-D_a}$$

A positive value for $(D_a - D_b)$ indicates a rise in elevation; a negative value, a drop in elevation.

Example: Given H = 10,000 feet, h_a = 395 feet, D_a = 51.96 MM, D_b = 50.90 MM, D = 127.50 MM. To find elevation of "b"

$$dh = \frac{(10,000 - 395)\ (51.96-50.90)}{127.50 - 51.96} = \frac{(9605)\ (1.06)}{75.54} = 134.8$$

$$h_b = h_a + dh = 395 + 135 = 530 \text{ feet}$$

The parallax equation may also be used to compute H, if the elevation of two points are known. For example, using above data to find H:

$$134.8 = \frac{(H - 395)\ (1.06)}{75.54} \qquad H = 10,000$$

412.3 CORRECTION OF PARALLAX MEASUREMENTS FOR PHOTO DISTORTION. The difference in elevation as computed in Article 412.2 is correct only if the photos are free from distortion due to tilt or processing, or to incorrect orientation in mounting the stereo pair. Correction for a warped datum plane can be made using the following formulas:

Difference in parallax measurement,

$$dp_x = \frac{(D-D_x) \quad hx}{H}$$

Parallax measurement to datum, $Dd = D_x + p_x$

Example: Given parallax measurements for three points of known elevation:

$D_a = 51.96$, $D_b = 50.90$, $D_c = 51.20$, $D = 127.50$, $H = 10,000$

$$dp_a = \frac{(127.50 - 51.91) \quad 395}{10,000} = \frac{(75.54) \quad 395}{10,000} = 2.98$$

$$dp_b = \frac{(127.50 - 50.90) \quad 536}{10,000} = \frac{(76.60) \quad 536}{10,000} = 4.11$$

$$dp_c = \frac{(127.50 - 51.20) \quad 472}{10,000} = \frac{(76.30) \quad 472}{10,000} = 3.60$$

D at datum for a = 51.96 + 2.98 = 54.94

D at datum for b = 50.90 + 4.11 = 55.01

D at datum for c = 51.20 + 3.60 = 54.80

The computed parallax measurements at datum are not constant, indicating a warped datum plan.

Select an assumed Dd. This is acceptable since it is the correction for parallax differences between two points that is required. Differences will be the same regardless of the Dd used.

CORRECTION TABULATION FORM

H = 10,000 ft. D = 127.50 MM

Point	h_x	D_x	$D-D_x$	h_x+H	dp_x	Computed	Assumed	Correction	Corrected D_x
a	395	51.96	75.54	0.0395	2.98	54.94	55.00	+0.06	52.02
b	536	50.90	76.60	0.0536	4.11	55.01	55.00	-0.01	50.89
c	472	51.20	76.30	0.0472	3.60	54.80	55.00	+0.20	50.40

The correction (Column 9) can be applied to the D_x of any other point "x" in the vicinity of a corrected point to correct for a warped datum plane. If a number of points of known elevation are distributed over the photo overlap, a correction isogram can be made on a transparent overlay. Interpolated correction lines are drawn in the same manner as isobars on a weather chart.

412.4 DISTANCE BETWEEN CONTROL POINTS BY RADIAL LINE PLOT. If a Kail or other mechanical plotter is available, the distances between control points may be found by plotting the control points and scaling the distances. Otherwise the following radial line plot method is suggested:

1. Orient a stereo-pair of photos so that flight lines are in perfect alignment and the distance from CP_2 to CP_1 = $\frac{(PP_1 \text{ to } CP_2) + (CP_1 \text{ to } PP_2)}{2}$

2. On a sheet of detail drawing paper or a transparent overlay, draw radial lines from PP_1 through road control points.

3. Draw radial lines from PP_2 through the same control points, intersecting the radial lines drawn from PP_1. The intersected points will then be in their correct relationship to each other, as on a map.

4. Scale the distance between the plots of adjacent control

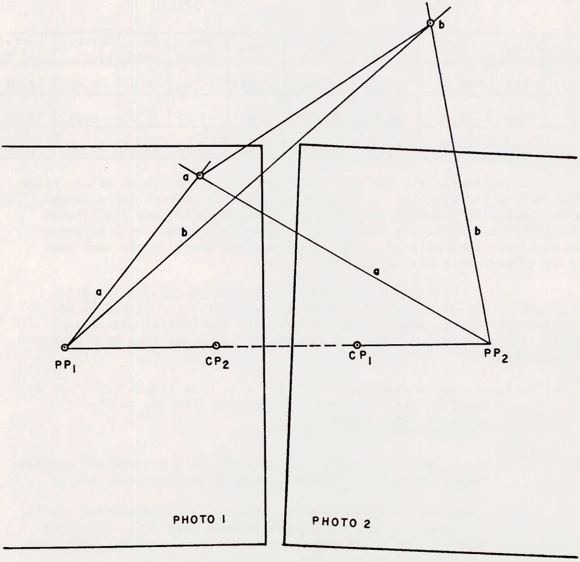
points. The plot scale is three times the average photo scale, computed at principal points, (because PP_1 to PP_2 = 3 times CP_2 to CP_1).

The photo scale R.F. = $\frac{\text{lens focal length "f"}}{\text{flight height above ground}}$ in the same units of measurement.

The focal length of the lens is shown on the terminal photos of the flight strip. If a ground distance is known, compute R.F. from $\frac{\text{Photo distance}}{\text{ground distance}}$.

FIGURE 412-2

RADIAL LINE PLOT



The photo scale in feet to the inch = $\frac{\text{flight height above ground}}{f}$

5. If the route between control points is not an approximately straight line which can be scaled, measure the distance under the stereoscope with a "Map Measure" (which has a measuring wheel and dial) or step off the route distance with dividers, following the approximate grade contour. Then, by proportion, the approximate route distance between two control points =

$$\frac{\text{radial plot distance x photo route distance}}{\text{photo straight line distance}}$$

The radial line plot method is illustrated in Figure 412-2.

412.5 PLOTTING GRADE LINE ON PHOTOS. If it is desired to plot points along a grade line between control points, compute the parallax measurement "Dx" for the elevation of each intermediate point "x".

> Example: Using the data given in example under 412.3, the distance between control points "a" and "b", which are 141 feet, the difference in elevation is measured as 2,800 feet, then the grade between control points is 141+2,800 = 5%. The elevation on grade at a point "x", halfway between control points, would be (395+536)/2 = 465 feet. The "Dx" for point "x" = (52.02 + 50.89)/2 = 51.45 MM. The point between control points is found by trial to have a distance of 51.45 MM between the images of the point at 465 feet elevation.

If a long grade line, such as a maximum sustained grade along a hillside, is to be plotted, the Bureau of Public Roads method of photogrammetric route projection (Article 412.7) is preferable.

412.6 MEASURING ELEVATION DIFFERENCES BY TEMPLET METHOD. Goodale(3_/) gives a rapid method by which parallax measurement to 0.1 MM give height differences within a range of ± 10 percent.*

*It does not require photo scale, flight height, or any known elevation. It does require a map distance measurement, "Bm" between principal points and the focal length "f" of the lens.

1. A templet is prepared by placing a sheet of transparent material, such as Dupont "Mylar", over the right-hand photo. With a fine-pointed needle, mark on the templet the principal points, and the two points for which difference in elevation is desired.

   Trace the base line between principal and conjugate points.

2. The templet is then placed over the left photo with the lower elevation point on the templet coinciding with the same point on the photo. Pivoting on the lower point, the templet is swung so that the base line on the templet is either superimposed or parallel to the base line on the photo. (If tilt or difference in photo scale due to difference in flight height, the base lines will not coincide and so are swung parallel.)

3. The principal point of the left photo is marked on the base line on the templet. The distances, "b_1" between the two principal points on the templet is measured. This is the photo base adjusted to datum of lower elevation point.

4. The upper elevation point on the left photo is marked on the templet.

5. Operations 2, 3, and 4 are repeated with the upper elevation points in coincidence. This gives a new principal point position of the left photo along the base line, and a new position of the lower elevation point. The parallax difference, "dp", between all three points is measured on the templet: (a) between the two principal point positions of the left photo along the center line, (b) between the two upper elevation points, and (c) between the two lower elevation points. If there is no tilt or error, the three measurements will be equal. If tilt exists, the "dp" least affected by the tilt (perceivable in stereo view) is used.

6. The difference in elevation "dh" is computed from the formula:

$$dh = \frac{(dp)\ (f)\ (Bm)}{b_1\ (b_1 + dp)}$$

Example: Given dp = 0.05", f = 8.25", Bm = 4,400 feet and b_1 = 3.33"

$$dh = \frac{0.05 \times 8.25 \times 4,400}{3.33(3.33 + 0.05)} = \frac{1,815}{11.25} = 161 \text{ feet}$$

If differences in elevation between a number of points are desired, the point of lowest elevation, is used as the datum. A single measurement of "b", serves for allppoints, and all differences in elevation are computed from the lowest point.

412.7 BUREAU OF PUBLIC ROADS METHOD OF PHOTOGRAMMETRIC ROUTE PROJECTION. The accompanying "Photogrammetric Work Sheet" is the form used by the Bureau of Public Roads for making computations for projecting road routes on aerial photos.

The formulas used are:

$$h = \frac{PH}{b + p} \qquad p = \frac{bh}{H-h} \qquad h = \frac{p(H-h)}{b}$$

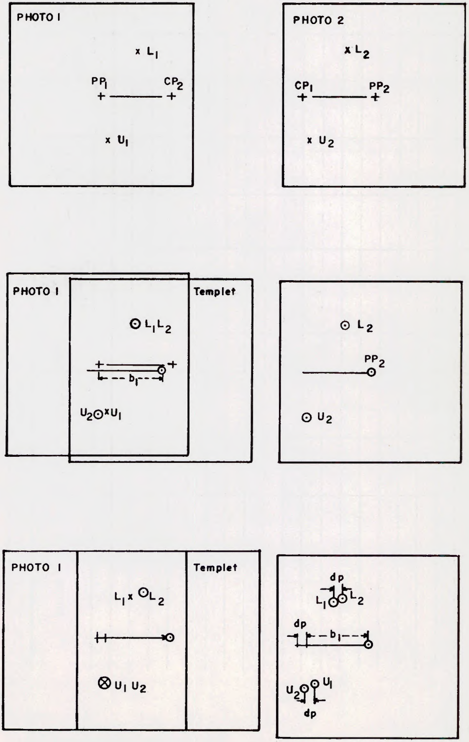
Scale in feet per inch, $S = \frac{H-h}{f}$

where "H" = flight height above datum in feet
"h" = image point elevation above datum in feet
"b" = distance between principal point and conjugate point on each photo (air photo base) in millimeters
"d" = parallax distances between two images of the same point in millimeters

FIGURE 412-3 ELEVATION DIFFERENCE BY TEMPLET METHOD

x= Elevation Point on Photo
o= Elevation Point on Photo

L= Lower Elevation Point
U= Upper Elevation Point



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DEPARTMENT OF COMMERCE

BUREAU OF PUBLIC ROADS

PHOTOGRAMMETRIC WORK SHEET

P. O. BOX 3900
PORTLAND 8, OREGON

$h = \frac{p\,H}{b + p}$, $p = \frac{b\,h}{H - h}$, $h = \frac{p(H-h)}{b}$, $S = \frac{H - h}{f}$ = (ft. per in.)

Sheet ____ of ____ Sheets

Date ________________

Project ____________________ No. __________

Section ______________________________

Instruments ______________________________

Location Engineer ______________________________

Photographs No. ______________ to ______________

Flight Altitude ______________________________

Flight Height (H) ______________ f ______________

b ______________________ b ______________

IMAGE POINT	d FOR PARALLAX	PARALLAX p	h FROM DATUM	H - h	SCALE FT. TO 1 IN. (S)	DISTANCE BETWEEN IMAGE POINTS			GRADE %	STATION	ELEV.	REMARKS
						VERTICAL	HORIZONTAL					
							IN.	FT.				

"p" = difference in feet between "d" for base point of known elevation and "d" for point of unknown elevation. A positive sign for "p" and "h" indicates a higher point of unknown elevation, a negative sign a lower elevation.

Computations for "h" or "p" are based on the larger of the two photo bases "b".

The procedure followed by the Bureau of Public Roads photogrammetrist is to lay out the photos by flights and study them for possible routes and control points. An approximate route between control points is then marked by a dotted line by eye under the stereoscope. Computations for grade line are customarily made by one inch increments ofophoto distance and the grade points plotted. After about five elevation points have been computed, a check back to the base elevation is made. If the grade elevations are starting to diverge, the ensuing projection is modified accordingly. To "turn" the route projection to an adjacent flight, the last elevation point is transferred to the side-lapped photo of the adjacent flight. This elevation point is used as the starting point for projection on the adjacent flight photos. It is preferable to make the projection downgrade, for the same reasons that a reconnaissance grade line is run downgrade. (Article 423.2) The route connecting grade points is marked with a solid line.

Example: Given: Flight altitude = 19,000 ft., flight height H = 14,000 ft. known elevation h = 5,000 ft. and b = 158.2. Elevation of starting point "0" is computed as follows (slide rule precision). Parallax distances measured with 50 scale.

Parallax distance for point "0"	460.1
Parallax distance for 5000' elevation	451.9
p =	-8.2

$$h = \frac{pH}{b+p} = \frac{-8.2 \times 14,000}{158.2 + (-8.2)} = \frac{-1148}{150} = -765$$

$$H - h = 14,000 - (-765) = 14,765$$

$$S = \frac{H - h}{f} = \frac{14,765}{6} = 2,460 \text{ ft. per inch}$$

Elevation of point "0" = 5,000 - 765 = 4,235

Computations for point "1" for 1 inch photo distance on a + 6% grade. Since elevation will be higher, scale "S", in feet to the inch will be smaller. Assume S = 2,440 ft/inch. Then 6% x 2,440 = rise of 146 ft., say 145 to nearest 5 ft.

Elevation of point "1" = 4,235 + 145 = 4,380
h = 5,000 - 4,380 = -620
H - h = 14,000 - (-620) = 14,620

$$p = \frac{bh}{H - h} = \frac{158.2 \times (-620)}{14,620} = \frac{-98,000}{14,620} = -6.7$$

$$d = 451.9 - (-6.7) = 458.6$$

Check on scale $S = \frac{14,620}{6}$ = 2,437 vs. 2,440 assumed. Correct to nearest 10 ft. distance.

The point at 1 inch photo distance which has a parallax distance of 458.6 will have an elevation of 4,380 and will be on a 6% grade line.

Computations for point "2" at 1" distance on a +6% grade.

Assume S = 2,420. Then 6% x 2,420 = 145 ft. elevation at point "2" = 4,380 + 145 = 4,525. h = 5,000 - 4,525 = -475. H - b = 14,000 - (-475) = 14,475. Check on scale S = 14,475/6 = 2,410. 6% x 2,410 = 144.6 = 145 ft. elevation OK

$$p = \frac{158.2 \times (-475)}{14,475} = \frac{-75200}{14,475} = -5.2$$

$$d = 451.9 - (-5.2) = 457.1$$

412.8 SLOPE MEASUREMENT FOR COST COMPARISON. An approximate cost comparison of alternate photo-projected routes can be made by determining side slopes on the photo and estimating quantities and construction costs in the same way as given in Article 411.6. Side slopes may be determined by computing horizontal distances and differences in elevation between points on each side of the route by any of the previously described photogrammetric methods, or by use of special instruments such as the "Stereo Slope Meter."

Choate(1/) gives a rapid method of determining slope percent with a parallax bar and a table of "Differential Parallax Factors." The photo scale is not required. A lower point and an upper point on the slope are selected. The photo distance in thousandths of feet between the two points is measured. The parallax distance between two points is measured to 0.01 mm. with the parallax bar. This measurement is converted to feet elevation difference (to the nearest .001) by using the table of "Differential Parallax Factors."

Then,

$$\text{Slope \%} = \frac{\text{Parallax Difference in feet} \times 100}{\text{Photo distance in feet between points}}$$

If elevation differences exceed 200 ft. the parallax formula should be used. If the points fall outside of the range of elevations of the principal point and the conjugate point, use the average of the distances between the elevation points and their conjugate images, measured parallel to the flight line, as the photo base, instead of the distance between principal and conjugate points, when entering the table.

Example: Given parallax distance 1.27 mm.; photo distance 0.25 inch = 0.021 feet; distance PP to CP 3.30 inches; f = 8¼ inches.

Differential parallax factor, from table = 0.000082
127 x 0.000082 = 0.0104

$$\text{Slope \%} = \frac{0.0104 \times 100}{0.021} = 49.5\text{, say } 50\%$$

The Differential Parallax Factor Table may also be used to obtain elevation differences when photo scale is known.

Example: Scale R. F. = 1 : 15,840

Elevation difference = .0104 x 15,840 = 165 ft.
0.25 in. at 1 : 15,840 = 3,960 in. = 330 ft.

$$\text{Slope} = \frac{165}{330} = 0.50 = 50\%$$

Study of Problem 12--Measuring slope percents, and Problem 13--Road planning on photos, in reference(2/) is recommended. This reference was supplied to all district offices June 7, 1960 by the Director, Bureau of Land Management.

DIFFERENTIAL PARALLAX FACTORS (1/)

Elevation Differences in Feet per .01 mm of Parallax Difference RF = 1 : 1

Distance between PP & CP	f = 8¼"	f = 12"
2.0 "	.000135	.000197
2.1	.000129	.000187
2.2	.000123	.000179
2.3	.000118	.000171
2.4	.000113	.000164
2.5	.000108	.000157
2.6	.000104	.000151
2.7	.000100	.000146
2.8	.000097	.000141
2.9	.000093	.000136
3.0	.000090	.000131
3.1	.000087	.000127
3.2	.000085	.000123
3.3	.000082	.000119
3.4	.000080	.000116
3.5	.000077	.000113
3.6	.000075	.000109
3.7	.000073	.000106
3.8	.000071	.000104
3.9	.000069	.000101
4.0	.000068	.000098
4.1	.000066	.000096
4.2	.000065	.000094
4.3	.000063	.000092
4.4	.000061	.000089
4.5	.000060	.000087
4.6	.000059	.000085
4.7	.000057	.000084
4.8	.000056	.000082
4.9	.000055	.000080

420 FIELD RECONNAISSANCE

421 INTRODUCTION

421.1 DEFINITION. By reconnaissance is meant the reconnoitering of the terrain in the field to determine a road route or to check a projected route. It includes all the field work preceding the preliminary or location survey in which angles or bearings are measured, distances taped and stakes set. Reconnaissance implies thorough investigation and analysis. The reconnaissance is completed when the final route has been determined, within narrow limits, and the grade line marked between control points. The major decisions affecting the route have been made and only minor adjustments may be required during the survey. The reconnaissance generally is made in two stages:

1. The extensive reconnaissance. This is a reconnaissance of area and major controls, embracing a relatively wide belt of land. The extent of the extensive reconnaissance will depend upon how much reliable information is available from maps and aerial photos.

2. The intensive reconnaissance. This is a reconnaissance of a selected route and minor control points. It embraces a narrow belt of land and establishes the line for the road survey.

421.2 OBJECTIVE OF THE RECONNAISSANCE. The objective of the extensive reconnaissance is to eliminate unfeasible routes and to decide upon the best route. The best route is the most economical route which serves the purposes for which the road is to be built. It is the route which will result in a road neither above or below the standards established for the class of road. If the route has been projected on large scale maps or aerial photos the initial reconnaissance will check the validity of the projected route. Control points may be encountered which did not show on the map or photo, necessitating changes in the projected route. Finding gravel deposits or pit-run rock for surfacing is another objective of the extensive reconnaissance.

The objective of the intensive reconnaissance is to mark on the ground the line which the survey is to follow. Usually a tagged or flagged grade line is run between control points.

421.3 IMPORTANCE OF THE RECONNAISSANCE. The importance of the reconnaissance cannot be overemphasized. It is during the reconnaissance that the major decisions should be made. The construction and maintenance costs, the transportation costs and the utility of the road are all affected by the reconnaissance. Good reconnaissance will avoid changes having to be made during the location survey, at greater cost than if made during the reconnaissance. Mistakes made during the reconnaissance are often difficult and expensive to correct later on.

Reconnaissance is hard work. The successful forest road engineer does not "give up" easily. He does not accept the first and most obvious route as "good enough" and fail to investigate all possible alternate routes. There is not substitute for "leg work" on reconnaissance.

Experienced forest engineers generally consider the reconnaissance to be the most important part of their work. The subsequent survey and design is viewed as relatively routine.

Ample time should be scheduled for the reconnaissance. Saving reconnaissance expense is unimportant compared with the savings in road costs and vehicle operating costs obtainable by allowing enough time to determine the best route.

421.4 SEASONS FOR RECONNAISSANCE. Weather conditions permitting, the best seasons of the year to make the reconnaissance are late autumn, after the deciduous leaves have fallen, winter, and early spring before the brush is in leaf. Visibility is greater and a wider belt of terrain can be seen. Tag lines can be run more efficiently as longer Abney sights can be taken and less time is wasted trying to find the sighting mark.

A background of experience in road location and construction is highly desirable for the reconnaissance engineer. Such experience will enable him better to visualize the constructed road along the route and avoid mistakes. The ideal program for the forest road engineer would be to spend the late spring, summer and early autumn on location and construction engineering, the periods of winter when weather precludes field work on route projection, and the other seasons on reconnaissance.

422 RECONNAISSANCE FOR UNPROJECTED ROUTE

422.1 EXTENSIVE RECONNAISSANCE. When the road route has not been first projected on large scale maps or aerial photos, an extensive reconnaissance precedes the intensive reconnaissance. Prior to going into the field, assemble all available small scale maps such as U.S.G.S. topographic quadrangles, and geological maps, and such maps of adjacent or intermingled private lands as are obtainable. Study these maps and the aerial photos of the reconnaissance area to find possible routes to investigate, and to plan the field work.

Plan the extensive reconnaissance so as to cover the belt of land embracing the possible routes in a systematic manner. Take the map and photos into the field. Whenever an identifiable section line is crossed, run a hand compass and pacing tie to a corner to fix your position. Keep track of direction by hand compass, of distances by pacing, and of elevations at identifiable points or at possible control points by aneroid barometer or altimeter. Mark them on the photos. Do not depend upon memory to compare alternative routes. Keep notes on the left hand pages of Field Book Form 301 and strip map sketch with form lines on the right hand pages. It is helpful in making the decision on the route for the intensive reconnaissance to build up a sketch map on 10 x 10 cross-section paper.

The high cost of surfacing of roads in some districts points to the desirability of keeping a sharp lookout for rock suitable for surfacing.

If the reconnaissance is for timber sale roads, keep the logging plan in mind. The road reconnaissance must be correlated with the logging planning.

422.2 JEEP ROADS. In planning the reconnaissance the possibilities of jeep roads into the area should be considered. If the reconnaissance requires walking long distances, the jeep road pays by saving travel time, allowing more time for productive work; by having the crew arrive at their starting point unfatigued; and eliminating back-packing to side camps. If the reconnaissance is for an access road, the savings in travel time of the Bureau of Public Roads location crew will more than pay for the jeep road. Jeep roads are also desirable in enabling the contractors who are prospective bidders to get out on the road location. The more they see of the survey the closer they can bid.

Jeep road grades depend on the soil, with a maximum of 25% under favorable conditions on sandy or gravelly soils where the jeep can get traction. The location and construction of a jeep road is an intermediate step between the extensive and the intensive reconnaissance for the unprojected route. It precedes the intensive reconnaissance for the projected route.

When the best route has been determined from the extensive reconnaissance, the intensive reconnaissance follows. This subject is covered under Section 423, "Reconnaissance for Projected Route," since Bureau of Land Management roads will generally be projected on large scale maps or aerial photos before the reconnaissance.

423 RECONNAISSANCE FOR PROJECTED ROUTE

423.1 FIELD CHECK. While projecting routes on large scale maps or aerial photos saves time by eliminating the extensive reconnaissance, it is still essential to check the projection on the ground. Conditions affecting the road location may be hidden by dense forest cover. The large scale maps, being made from aerial photos, may also be affected by dense cover.

Take a print of the map and the stereo-pairs of photos on which the route has been projected, and a pocket stereoscope, into the field. Follow the projected route, identifying successive control points on the ground, and check their validity. Check elevations on the ground with aneroid or altimeter. Pace distances between control points. If elevations or distances differ appreciably from the projection, calculate the apparent grade between control points, and run a trial line back.

Watch for soft or wet ground or rock ledges which were obscured on the photos. Check the suitability of projected landings, if they are control points. Check projected stream crossings and investigate the possibility of better crossings upstream or downstream which can be reached within grade limitations. Make certain that the projected route is feasible before starting the intensive reconnaissance.

Even if a map-projected route is followed, it is desirable to take the aerial photos covering the route into the field. Correlating conditions on the ground with their appearance on the photos will improve the observer's photo-interpretive ability.

423.2 INTENSIVE RECONNAISSANCE. The control points having been identified and checked, and the grade between them computed, the tag line is run down-grade. The reason for running down is that the terrain is widening out and opening up giving more leeway for the tag line. If a tag line is run up-grade the narrowing valleys restrict the line.

Because of the grade limitations on Bureau of Land Management roads, and the elevations to be reached, the tag line will often be run at or near the maximum permissable grade. The grade line on the ground is analogous to the "grade contour" stepped off with dividers on the topographic map. If the grade line hits above or below the lower control point, obtain the difference in elevations with the Abney and compute the corrected grade percent. Tag the corrected grade line back. Remove the tags or flagging tape on the abandoned line.

Two types of tag lines are run by forest engineers. The tag line of one type represents the center line of the road. On steep side slopes where heavy cuts on center line are required, the tag line is adjusted up-hill and the preliminary or direct location survey approximately coincides with the tag line. This type is best adapted to rolling terrain or moderate side slopes.

The other type of tag line represents the grade of the constructed subgrade and the location survey is run parallel to and above the tagged grade line to get the required cut on center line. This type is best adapted to steep side slopes where much of the subgrade is to be benched.

In tagging a grade line keep the road alignment in mind. Alignment is just as important as grade. Do not turn an angle more than half the maximum degree of curve per station from or to a tangent, nor more than the degree of curve per station from the chord of a curve. Use the hand compass to turn angles. In running to maximum grade guard against the tendency to concentrate on the grade and forget the alignment.

423.3 RUNNING GRADE LINE. Following is recommended procedure for a two-man party: The Abney man notes the point on the helper's face or hat which is the same height as his "H.I." or eye height. The Abney man walks ahead and, with his Abney set at the percent grade being run, sights back on the helper who stands at the last grade point. (The Abney man can place himself on grade more quickly than he can direct a helper to move up or down hill to get on grade). A bright aluminum safety hat makes a good sighting mark under ordinary conditions. In brushy ground cover or on dark or rainy days the helper holds a flashlight at H.I.

When the Abney man finds his grade point, he kicks a spot on the ground clear with his feet, to mark where he stood, and places a red tag or piece of flagging tape on the nearest tree. Some engineers prefer to set the tag at H.I. above the ground. He takes a grade sight with the Abney ahead along the slope to get his direction, and walks ahead. The helper comes ahead, tagging the line as he goes. Arriving at the tag set by the Abney man he looks for the spot cleared by the Abney man and occupies it. By this time the Abney man has reached the vicinity of the next grade point, and repeats the above procedure. The tag interval will depend upon the density of the ground cover. The tags should be intervisible. Avoid short Abney shots which tend to make the grade line longer than the location line with consequent increase in location grade. As about the same amount of time is taken by each shot, the longer the shots the more line a party can run per day. However, shots which are too long waste time in trying to find the sighting mark.

In running a grade line without a helper, the Abney man sets a tag at his H.I., sights ahead along the slope, and sets tags as he goes ahead. When he has gone as far as he can see the tag set at his last grade point, he sights back on the tag and sets a new grade point.

The more experience the Abney man has in road location and construction the better job he can do on reconnaissance. He should visualize the alignment and profile of the constructed road along the grade line.

423.4 RUNNING GRADE LINE FOR CURVES. A mistake commonly made in running a grade line around a sharp-nosed ridge, or a narrow valley, is in tagging a line longer than the length of the curve which will be located. This results in a steeper grade on the located curve than was intended. When tagging to a maximum grade this may result in the location exceeding the allowable maximum. The inexperienced man tends to tag around the semi-tangents of the curve rather than the curve. (Figure. 423-1)

The experienced engineer will estimate the degree and length of the curve and reduce the grade on the tag line to compensate for the difference in length between the tag line and the final located curve. By reading the intersection angle with the hand compass, and estimating the appropriate degree of curve, the length is calculated from $L = 100\Delta/D$ running a grade line on the maximum allowable grade for the class of road, setting the Abney arc at ½ or 1 percent under the maximum grade will help to insure that the maximum grade is not exceeded on the location. The grade line tends to follow minor curves on the ground which are eliminated by tangents on the location. Following are methods by which the less experienced man may do a better job of tagging the grade line for sharp curves:

1. Tagging around a sharp ridge. Run grade line to nose of ridge. Take hand compass bearing back along the tag line and forward parallel to the grade on the forward tangent. Compute the intersection angle Δ. Estimate the degree of curve required (usually the maximum allowable) and calculate the semi-tangent. Pace back to the S. T. distance to the P.C. Then either

   a. Read the percent up to the crest of the ridge in the direction of the long chord. (Deflection angle of $LC = \Delta/2$). Pace the distance. Take an Abney shot the same percent down and pace the same distance. This will put you on the same elevation as the P.C.

b. With the Abney set at 0 percent, run level around the ridge to the approximate P.T. opposite the P.C.

Compute the length of curve L and the difference in elevation between P.C. on P.T. on the desired grade for the curve. Lay off this difference from the approximate P.T. point. Continue tagging the grade line along the next tangent.

Example: Running maximum 10 percent favorable grade line grade for class III road. Hand compass bearing of tangents from nose of ridge N 50° E and S 70° E. Δ = 120°. From "Calders' Forest Road Engineering Tables", Table 11, LC and ST = 9924 conditions indicate maximum 75° curve ST = 9924/75 = 132 ft. L = 100 Δ /0 = 12,000/75 = 160 ft. 160 x 10% = 16 ft. difference in elevation between P.C. and P.T. Distance via STs = 132 x 2 = 264 ft. grade via STs = 16/264 = 6%. Direction of LC = deflection angle 60° from S 50°W = S 10° E Length of LC = 9924/75 = 132 ft. (Fig. 423-1)

2. Tagging across a narrow valley. The method given above for ridges may be used in valleys by running the grade line to the PI at the creek. However, since the PC and PT are usually intervisible, it may be more convenient to work from the long chord. Take a back bearing along the tangent, shoot a level shot across the valley in the estimated direction of the L.C. and pace the distance. Take a forward bearing along the forward tangent grade percent and compute the Δ . Compute the degree of curve from LC_1°/LC. Compute the difference in elevation between P.C. and P.T. for curve L and desired grade. If the tangents are nearly parallel, as in a box canyon, select the points for the P.C. and P.T., pace the L.C. between them and compute radius of curve from LC/2. This method is also useful in tagging switch-backs.

Example 1: Backing bearing from assumed P I N 70° W. Length of approximate LC = 160 ft. Forward bearing S 30° W. Δ = 100° LC from Calders' Table 11 = 8778. Degree of curve = 8778/160 = 55° L = 10,000/55 = 182 ft. 182 x 10% = 18 ft. difference in elevation between PC and PT. Grade along LC = 18/160 = 11% Bearing of LC = S 70°E - 50° = S 20° E. Run S 20° E 160 ft. on 11% to P.T. Then proceed on 10% grade in direction of forward tangent. (Fig. 423-1)

Example 2: Box Canyon, tangents to curve approximately parallel. LC paced 190 ft. Radius of curve = 190/2 = 95 ft. Degree of curve = 60° L = 18,000/60 = 300 ft. Abney reading between PC and PT 12% difference in elevation 12 x 190 = 23 ft. Grade on curve 23/300 = 7.7%.

Where a curve is a critical part of the tagged line, it may be tagged by turning deflection angles with the hand compass (from PC or PT

FIGURE 423-1 PLAN

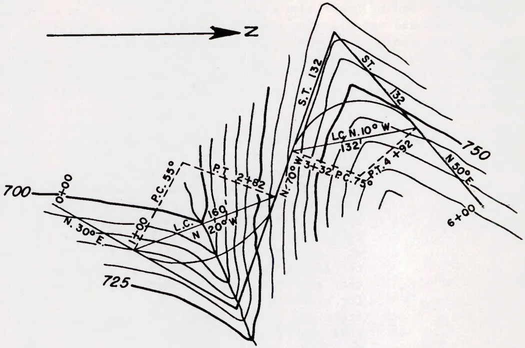
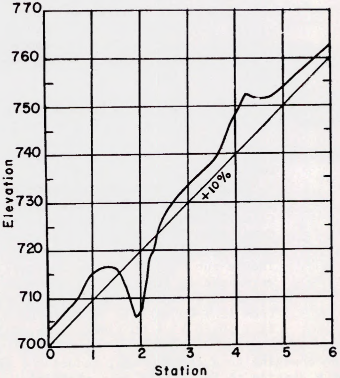


FIGURE 423-1 PROFILE



deflection for 100 ft. = one-half the degree of curve) and pacing stations, or by estimating middle ordinate distances.

423.5 GRADE SEPARATION AND VERTICAL CURVES. Other common mistakes in running grade lines are (a) branching off too abruptly from another road and not allowing enough room for grade separation, and (b) not allowing enough room for a vertical curve at grade breaks such as reducing grade for a landing. The grade on a spur road branching off of a main road must coincide with the grade of the main road until the center lines of the two roads are separated by the sum of the half-widths at the two road sub-grades.

Example: Class III spur with a half-base on the outside of the center line of 10 ft. to take off on a 25° curve on a 300 ft. vertical curve leading to a + 10% maximum grade, from a class II main road with a half-base on the ditch side of 13 ft. on a + 2% grade. Reference to Calders' Table 7, "Tangent Offsets," grade separation for a little less than 23 ft. will take place at Station 1 + 03 (actually at 1 + 02). Reference to Calders' Table 10 "Vertical Curve Offsets" shows that the offset at the vertex of the vertical curve for a change in grade of 8% is 3 ft. Therefore, start the grade line at the elevation of the main road subgrade 103 ft. from the selected P.C. Rise in 150 ft. to PVC at 2% = 3 ft. + 3 ft. offset = 6 ft. 6/150 = 4%. Run + 4% for 150 ft. to the middle of the vertical curve. Rise in 150 ft. from vertex at 10% = 15 ft. - 3 ft. offset = 12 ft. 12/150 = 8%. Run + 8% 150 ft. to the end of the vertical curve, thence run + 10%. (Fig. 423-2) If the 10% grade line were started at the P.C. 0 + 00 it would be 20.3 ft. too high at station 4 + 03; if started at 1 + 03 it would be 10 ft. too high at 4 + 03.

In running a grade line into a landing where the grade must be reduced, care must be taken to allow room for a vertical curve.

Example: Spar tree and landing at Station 12 + 50, + 3% grade wanted from 12 + 00 to 13 + 00. Approaching on a + 10% grade, reduction in grade for a 200 ft. vertical curve must begin at Station 10 + 00. From Calders' Table 10, offset at 11 + 00 is 1.75 ft. Grade from 10 + 00 to 11 + 00 = 10 - 1.75 = 8.25%. Grade from 11 + 00 to 12 + 00 = 3 + 1.75 = 4.75%. Thence run 3%. If the grade break from 10% to 3% were made at Station 12 + 00, when the road was constructed with a 200 ft. vertical curve, the grade from 12 + 00 to 12 + 50 would be 5.6% and from 12 + 50 to 13 + 00 3.9%. (Fig. 423-3)

When changing to a steep grade, reduce the preceding grade 1 or 2 percent for a station to facilitate gear shifting.

FIGURE 423-2 GRADE SEPARATION PROFILE

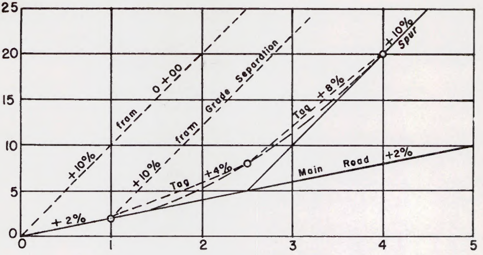


FIGURE 423-2 PLAN

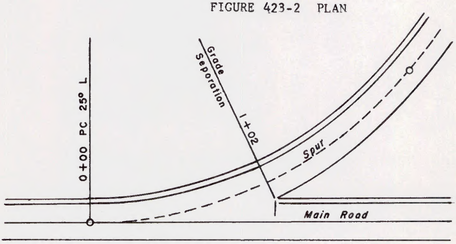
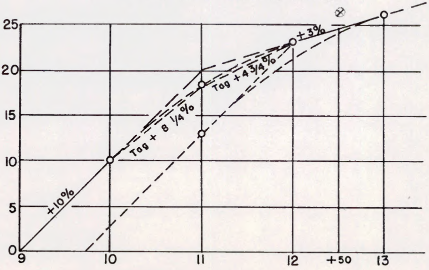


FIGURE 423-3 LANDING PROFILE



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CONTENTS

500 ROAD LOCATION SURVEYS

510 INTRODUCTION

511 CLASSIFICATION

511.1 SURVEY CLASSES. For convenient reference, the following classification of road surveys is made:

Class "A". Surveys comparable to the type of survey made for access roads by the Bureau of Public Roads. This is the highway engineer's method. The preliminary traverse is run with transit and steel tape, elevations being obtained with engineer's level and rod. A belt of topography along the preliminary line is mapped and the road is designed from the topography. Precision is third order, or 1 in 5,000.

Class "B". Road surveys made by the "contour offset" design method, or by direct center line location. Traverse is by staff compass and steel tape. Levels are by hand level and rod or double-Abney. Design by the contour offset method is usually done in the office. Design by the direct location method is done in the field. With care, precision of 1 in 500 is obtainable.

Class "C". The class "C" road survey is little more than a staked tag line. Station stakes are set by chaining along the tag line and single Abney readings are taken between stakes for profile elevations. Curves are run in by eye without computation. On sharp curves, a hand compass deflection bearing or middle ordinates are used to ensure that the turning radius of a log truck and trailer is not exceeded. No traverse is run unless required for right-of-way acquisition or for plotting the road on a map. Where a traverse is required, the curves are not staked. An external stake is set to mark the middle of the curve. Where the external indicates an appreciable difference in length between the curve center line and the sum of the two semi-tangents, the PI equation is computed and the forward stationing carried from the "Ahead" PI station.

511.2 CHOICE OF SURVEY CLASS. The choice of survey class and method will depend upon due consideration to the following factors:

1. Standard of road. The higher the standard of road, the higher the class of survey which is economically justified. Generally, a class I road calls for a Class "A" survey; class II and class III road for a Class "B" survey; and sub-standard temporary spur road for a class "C" survey.

2. Topographic difficulties. The more difficult the terrain, the higher the class of survey necessary to avoid mistakes in location. Where the topography is steep and broken and cuts and fills large, the Class "A" survey is advisable. For ordinary side hill location, the contour offset method Class "B" survey is suitable. The experienced location engineer wil find direct location the most time-saving on moderate slopes or rolling topography. Class "A" survey of portions presenting

difficult problems in location may be combined with Class "B" survey.

3. Engineering supervision of construction. The class of survey should be commensurate with the degree of engineering supervision of construction which can be given. There is no point in making a high class survey for an operator-built road if an engineer will not be available during construction. In this connection, the importance of providing adequate engineering supervision, to ensure that a road is built as designed, should be recognized by forest managers. Usually the road system for a sustained yield operation must be financed by the harvest of the old-growth. The original construction, with adequate drainage facilities and stable side slopes, within the alignment and gradient limits of the road standard, and with the correct depth of surfacing for the subgrade soil, is the basis of permanence. Engineering supervision of construction is essential to achieve this.

4. Personal factors. The training and experience of the road locator is a factor in the choice of survey method. The less experienced or less qualified man would have to use a higher class method to obtain as good results as a more experienced, qualified man would achieve with a lower class method. The road survey program should be planned well in advance so that sufficient time is allowed to permit use of the method called for by the other factors. Provision should be made for enough personnel trained in forest road engineering (such as logging engineering or forest engineering graduates) to do the job of road location and construction engineering which is needed.

512 FIELD NOTES

512.1 FIELD NOTE-KEEPING.

It is of the utmost importance that all engineering field notes be kept legibly in standard form. Field notes must be as comprehensible to any other engineer as they are to the note keeper. This necessitates following standard forms of notes. Field notes must be legible and complete. Anything which is not a part of the routine notes, such as a tie or an offset, should be amplified by a sketch on the right-hand page. All equations must give back (Bk) and ahead (Ah) stationing. Date, names and jobs of the party members, equipment and weather should be printed in the upper right-corner of the field book page at the beginning of each day's work. Each page, consisting of a combined left-hand and right-hand page in the field book, is numbered. Do not crowd notes. Make no erasures. The last station on the previous page should always be repeated as the first station on the next page. Use only standard abbreviations (Article 512.2). The field book should be labeled with district, unit, project name and number, kind of survey, and book number.

The growing use of electronic computation of road surveys and design is another reason for keeping legible notes in standard form. Notes are not transcribed, but are used by the card punch operator as recorded in the field. Card punch operators are not engineers so nothing can be left to their interpretation, and no deviation from standard notes can be permitted. The field note form Figure 522-1 is suitable for electronic computation. Available programs are outlined in Section 715.

512.2 STANDARD ABBREVIATIONS. Following is a list of the standard abbreviations used, in part, in this Handbook and recommended for field notes. If any other abbreviations are used, they should be explained in the field book.

ABBREVIATION	MEANING	ABBREVIATION	MEANING
Abut.	Abutment	L.R.	loose rock
Ac.	Acre	Lt.	left
Ah.	Ahead	L.W.	low water
A.P. or $\triangle$	Angle Point	Mag.	magnetic
bdy.	boundary	Mi.	mile
Bk.	back	M.O.	middle ordinate
B.M.	bench mark	N	North
bor.	borrow	O.H.	overhaul
br.	bridge	OTC	open top culvert
C.	cut	P-line	preliminary survey line
Calc.	calculated	Pt.	point
cl.	clearing	P.C.	point of curve (beginning of curve)
℄	center line		
CMP	Corrugated Metal Pipe	P.C.C.	point of compound curve
C.O.	Chord offset	P.I.	point of intersection of tangents
Com.	Common		
conc.	concrete	P.O.C.	point on curve
Cor.	corner	P.O.S.T.	point on semi-tangent
C.O.P.	Chief of Party	P.O.T.	point on tangent
Cr.	Creek	P.T.	point of tangency (end of curve)
Cul.	Culvert		
C.Y.	Cubic Yard	R	radius of curve
D	Degree of curve	R.C.	Rear Chainman
dep.	departure	R.C.P.	reinforced concrete pipe culvert
dr.	drainage		
E	East; external on plan	Rod	rodman
ea.	each	R.P.	reference point
Elev.	Elevation	rt.	right
emb.	embankment	R/W	right-of-way
E.R.	edge of road	S	South
E.X.	external of curve (Calder)	sec.	section
exc.	excavation	sel.	selected
E.W.	edge of water	Sl.	slope
F	fill	S.R.	solid rock
fn.	fence	S.S.	slope stake
Fwd.	forward	SS	side slope
H.C.	Head Chainman	S.T.	semi-tangent (of curve)
H.I.	Height of Instrument	Sta.	station (100 ft.)
H.W.	high water	Std.	standard
I.P.	Intermediate point (on P-line)	Surf.	surfacing
		T	tangent (between curves)
L	length of curve	T.O.	tangent offset
lat.	latitude	T.P.	turning point
L.C.	long chord	T.O.S.	toe of slope
L-line	location survey line	Uncl.	unclassified

V. or V.P.I.	vertex of vertical curve
Var.	magnetic variation (declination)
V.C.	vertical curve
W	West
Wi.	widening
W.L.	water level
X.S.	cross-section

+S or B.S.	Back sight
-S or F.S.	Fore sight
△	intersection angle at PI
	instrument man
#	number
	swamp or marsh
	rock

FIGURE 512-1 PERCENT TRIGONOMETRIC TABLES

%	Ver. X 100	Sine X 100	Exsec X 100	Cotan X 10	%	Ver. X 100	Sine X 100	Exsec X 100	Cotan X 10
0	.0	.0	.0	o-o	46	9.1	41.8	10.1	21.7
1	.0	1.0	.0	1000.0	47	9.5	42.5	10.5	21.3
2	.0	2.0	.0	500.0	48	9.8	43.3	10.9	20.8
3	.0	3.0	.0	333.3	49	10.2	44.0	11.4	20.4
4	.1	4.0	.1	250.0	50	10.6	44.7	11.8	20.0
5	.1	5.0	.1	200.0	51	10.9	45.4	12.2	19.6
6	.2	6.0	.2	166.7	52	11.3	46.1	12.7	19.2
7	.2	7.0	.2	142.9	53	11.6	46.8	13.2	18.9
8	.3	8.0	.3	125.0	54	12.0	47.5	13.6	18.5
9	.4	9.0	.4	111.1	55	12.4	48.2	14.1	18.2
10	.5	10.0	.5	100.0	56	12.8	48.9	14.6	17.9
11	.6	10.9	.6	90.9	57	13.1	49.5	15.1	17.5
12	.7	11.9	.7	83.3	58	13.5	50.2	15.6	17.2
13	.8	12.9	.8	76.9	59	13.9	50.8	16.1	17.0
14	1.0	13.9	1.0	71.4	60	14.3	51.5	16.6	16.7
15	1.1	14.8	1.1	66.7	61	14.6	52.1	17.1	16.4
16	1.3	15.8	1.3	62.5	62	15.0	52.7	17.7	16.1
17	1.4	16.8	1.4	58.8	63	15.4	53.3	18.2	15.9
18	1.6	17.7	1.6	55.6	64	15.8	53.9	18.7	15.6
19	1.8	18.7	1.8	52.6	65	16.1	54.5	19.3	15.4
20	1.9	19.6	2.0	50.0	66	16.5	55.1	19.8	15.2
21	2.1	20.6	2.2	47.6	67	16.9	55.7	20.4	14.9
22	2.3	21.5	2.4	45.5	68	17.3	56.2	20.9	14.7
23	2.5	22.4	2.6	43.5	69	17.7	56.8	21.5	14.5
24	2.8	23.3	2.8	41.7	70	18.1	57.4	22.1	14.3
25	3.0	24.2	3.1	40.0	71	18.5	57.9	22.6	14.1
26	3.2	25.2	3.3	38.5	72	18.8	58.4	23.2	13.9
27	3.5	26.1	3.6	37.0	73	19.2	59.0	23.8	13.7
28	3.7	27.0	3.8	35.7	74	19.6	59.5	24.4	13.5
29	4.0	27.8	4.1	34.5	75	20.0	60.0	25.0	13.3
30	4.2	28.7	4.4	33.3	76	20.4	60.5	25.6	13.2
31	4.5	29.6	4.7	32.3	77	20.8	61.0	26.2	13.0
32	4.8	30.5	5.0	31.2	78	21.1	61.5	26.8	12.8
33	5.0	31.3	5.3	30.3	79	21.5	62.0	27.5	12.7
34	5.3	32.2	5.6	29.4	80	21.9	62.5	28.1	12.5
35	5.6	33.0	5.9	28.6	81	22.3	62.9	28.7	12.3
36	5.9	33.9	6.3	27.8	82	22.7	63.4	29.3	12.2
37	6.2	34.7	6.6	27.0	83	23.1	63.9	30.0	12.0
38	6.5	35.5	7.0	26.3	84	23.4	64.3	30.6	11.9
39	6.8	36.3	7.3	25.6	85	23.8	64.8	31.2	11.8
40	7.2	37.1	7.7	25.0	86	24.2	65.2	31.9	11.6
41	7.5	37.9	8.1	24.4	87	24.5	65.6	32.5	11.5
42	7.8	38.7	8.5	23.8	88	24.9	66.1	33.2	11.4
43	8.1	39.5	8.9	23.3	89	25.3	66.5	33.8	11.2
44	8.5	40.3	9.3	22.7	90	25.7	66.9	34.5	11.1
45	8.8	41.0	9.7	22.2	91	26.0	67.5	35.2	11.0

512.3 FIELD BOOKS. Engineers differ in their preferences for bound or loose-leaf field note books. The loose-leaf notes are more convenient to file and to refer to, but there is always the risk of losing a page. For wet weather the 24-page "Waterproof Field Book Filler" is recommended. The filler is intended to be inserted in a leather cover, but may be used as it is.

In addition to the field note book, the notekeeper usually carries a book of mathematical tables and a 5-inch pocket slide rule. For transit surveys the tables in the appendix to the route survey textbook are used. For compass surveys, Calders' "Forest Road Engineering Tables" are recommended. When the percent Abney level is used and slope distances are measured, the percent trigonometric tables given in Figure 512-1 are very helpful. These tables were compiled by Prof. John O'Leary, Forest Engineering Department, School of Forestry, Oregon State College. Copies suitable for pasting in the field book are available from the Oregon State College book store, Corvallis, Oregon. The tables give the following data:

1. The "versine X 100" gives the difference between the slope distance and the horizontal distance for each 100 feet of slope distance.
2. The "sine X 100" gives the difference in elevation for each 100 feet of slope distance.
3. The "exsecant X 100" gives the difference between the slope distance and the horizontal distance for each 100 feet of horizontal distance.
4. The "cotangent X 10" gives the horizontal distance between 10 foot contours.

513 DETECTING SURVEYING ERRORS

513.1 SYSTEMATIC CHECKING. The possibility of making errors or mistakes is involved in every step of the surveying process. The stresses imposed by field conditions in forest surveying are especially conducive to errors. It is essential that all members of a survey party develop the habit of making systematic checks to detect errors due to mishandling of instruments, or mistakes made in reading them. So far as possible, the check should be made a different way, as repeating the same operation may result in repetition of the error. Procedures to check chaining, stationing, compass reading, and leveling follow. Every member of the survey party should read Section 513. Checks on computations and staking of curves are given in Section 532.

513.2 CHAINING AND STATIONING.

1. Chaining. Before taking a reading or setting a station stake, the chainmen check that the tape is straight, taut and level (or held at the same HI when slope chaining). When reading a tape, speak the numbers aloud. Say "seven zero", not "seventy". Say "seven zero point five" for 70.5. Reading is checked by looking at the adjacent foot mark and comparing it with the reading called. This will detect the mistakes caused by confusion between 6 and 9,

3 and 8 or the wrong tens of feet. Use of standard voice signals, such as the head chainman responding "Stuck!" to the rear chainman's call of "Stick!" is recommended.

2. Stationing. The following standard procedure will avoid mistakes in stationing: The rear chainman calls the tenths he is adding, unless he is chaining to the zero mark, and the new station he is staking. The rear chainman calls "Check!" if the new station is correct, or "No!" if he disagrees. Example: Rear chainman "6+50 holding 50". Head chainman "7+zero". Rear chainman "Check". When the compassman goes ahead, he should check the stakes to ensure that there have been no duplications or omissions in stationing.

513.3 COMPASS READING. Before reading a staff-compass bearing the compassman sees that no metal which would attract the needle is on his person or near the compass. He notes the position of the level bubble and whether the needle is oscillating. He notes the quadrant and whether it agrees with the general direction of the course. He checks the needle to ensure that he reads the North end. Finally he reads the degrees and counts forward and back to ensure that he does not read the wrong side of 10°, (as 39° for 41°). He checks the quadrant again, if the needle is near 0° or 90°. After the bearing has been recorded, he reads it again for a check. Local attraction is checked by always reading back bearings as well as forward bearings. Keep camera light meters away from the compass.

513.4 LEVELING. Marking the "plus" and "minus" sides on the Abney quadrant will help to avoid mistakes in signs in Abney leveling. Readings are made by counting forward, checked by counting back from the next 10 percent mark. Handling the Abney arm so that it stops when the bubble is bisected by the cross-hair, when the cross-hair is on the sighting mark, is a matter of skill developed by practice. For common errors and mistakes in differential leveling, see any plane surveying text. It is advisable to check rod readings on turning points by the rodman holding a red tag at the reading called by the levelman and checking the intercept. Readings beyond arm reach can be checked by placing the top of the rodman's axe on the mark. Computing TP elevations in the field, and noting whether the next TP is lower or higher than the preceding TP, and whether the difference in elevation looks reasonable, will detect mistakes in entering foresights or backsights in the wrong column, or mistakes in arithmetic or in rod reading. Speak all readings aloud.

513.5 GROSS CHECKS. Gross checks by eye are valuable to detect the large errors. The members of a survey party can and should develop the ability to estimate distances, slopes, differences in elevations, and horizontal angles on the ground. Before or after every reading of surveying instruments, the operator should check by looking to see whether the reading appears reasonable on the ground. The better practice is to make the estimate before the reading. Then if the reading does not check with the estimate, it can be immediately repeated. Swinging the arms through the intersection angle, before computing the $\triangle$, will give a gross check on mistakes in computation. In concentration on the fine reading, such as the ½ or ¼ degree or percent or the rod tenth or hundredth, the operator may make a far more serious error in the whole degree or foot or in the tens.

513.6 CHECKING INSTRUMENT ADJUSTMENT. The degree of precision consistent with the surveying method adopted, can be attained only if the instruments are in adjustment. Instruments should be checked, and adjusted if necessary, at the beginning of each day's work. If dropped or jarred during the day, the instrument should immediately be checked. Abney levels are particularly susceptible to getting out of adjustment. Instrument checks include whether the correct declination is set off on the compass, and whether the needle is sluggish.

520 CLASS "A" SURVEYS

521 HIGHWAY ENGINEER'S METHOD

521.1 TRANSIT LOCATION. The highway engineer's location method is covered in detail in every route survey or highway engineering text book. It is, therefore, only outlined briefly here. Following are the consecutive steps:

1. Transit preliminary. A transit traverse P-line is run along the route of the road. Intermediate stakes are set at every station.

2. Leveling. Levels are run with engineer's level and rod. The self-leveling level is the most efficient in saving time in setting up.

3. Topography cross-section. Cross-sections are taken at each station to or beyond the possible limits of location and construction. The old way is to locate each 5-foot contour, with hand level and rod, and measure the distance to it. The newer way is to take side slopes with clinometer or Rhodes arc and to convert to contour interval and distance by electronic computation (Section 715). Notes are made of topographic features.

4. The P-line traverse is plotted by coordinates on a scale of 1 inch = 100 feet, the contour points plotted at each cross-section, and connected with contours at 5-foot contour interval. Thus, a topographic map is built up in a narrow belt along the route of the P-line.

5. Control points are selected and a "grade contour" stepped off with dividers along the contours. Using the grade contour as a guide, the L-line is paper located.

6. A trial profile is read off, and trial end area cross-sections made, by interpolating elevations on the map. The L-line is revised in accordance with the information obtained from trial profile and earthwork computations, until the best location is reached. Coordinates of PIs are scaled, and bearings and distances and curve data computed.

7. Right-of-way clearing stakes are set in the field, from the P-line, and referenced.

8. After the right-of-way is cleared, the L-line is run in the field by transit, checked by ties from the P-line, setting station and +50 stakes and PC, PI, and PT stakes for each curve. Stakes on the curve are set by transit deflection angles. The L-line is well referenced.

9. Levels on the L-line are run with engineer's level, the profile is plotted and the grade line fitted.

10. Slope stakes are set with hand level and rod, or Rhodes arc, and tape. Earthwork quantities are computed.

11. Culverts are designed and staked.

12. Construction cost estimates are made. The Bureau of Public Roads makes cost estimates after Step 7, and before Step 8.

522 LOGGING ENGINEER'S MODIFICATION

522.1 CONDITIONS TO WHICH ADAPTED. The economy of the staff compass traverse, and the lesser precision required for truck logging roads, has led to a modification by logging engineers of the highway engineers method. This modified method is detailed in Articles 522.2 to 522.8. It is adapted to rough, broken topography, where heavy cuts and fills are involved. It is often used for short portions of routes otherwise located by Class "B" surveys, where topographic difficulties indicate the desirability of paper location. The less experienced road locator can do a better job with this method since he can make trials and revisions in the office until he finds the best location.

522.2 PRELIMINARY LINE TRAVERSE. The P-line traverse is run with staff compass and tape in the same way as described in Article 531.3, except that intermediate stakes are set at each station. Side slopes are not taken except when the electronic topographic program is to be used (Section 715). Leveling is done with engineer's level and rod.

522.3 TRAVERSE PLOT. The P-line traverse is plotted on a detail paper "hardshell" to the scale of 1 inch = 100 feet with the drafting machine. Perpendicular lines are drawn at each station with the other arm of the drafting machine. The traverse and perpendicular lines are traced on heavy tracing paper, in strips which will fit a Tatum holder. The station number and elevation is printed at the end of the perpendicular line. These strips are taken into the field for drawing topography, distances being scaled with a 6-inch pocket scale. An alternative method is to prick, with a needle, the traverse through on to strips of 10 x 10 cross-section paper, with the lines oriented in cardinal directions. Topography shots are taken in cardinal direction obtained with a hand compass. The ruled lines give the distance scale. Distances between the 0.1 inch lines (10 feet in the ground) are interpolated by eye.

522.4 FIELD TOPOGRAPHY. On steep slopes, cross sections are taken by Abney level and slope chaining, converted to horizontal distance and difference in elevation. Use of the percent versine table greatly facilitates this conversion. (Fig. 512-1) Elevation points are plotted, 5-foot contour points interpolated, and contours connecting them are drawn

FIGURE 522-1 COMPASS P-LINE FIELD NOTE FORM - CLASS "B" SURVEY

Page 1 Road No. 23-8-14

Sta.	Hor. Dist.	Calc. Brg.	Mag. Brg. Back	Mag. Brg. Fwd.	Defl. L	Defl. R	Slope Dist.	Abney %
9+00								
	199$^{\pm}$	SOUTH					200	+8
$7+00^{6}$			N 10 3/4 W	SOUTH		10 3/4		
	100^{8}	S 10 3/4 E						
$5+99^{8}$			N 24 1/2 W	S 10 3/4 E		13 3/4		
	99^{8}	S 24 1/2 E					100	+6
5+00			N 33 1/2 W	S 26 E		7 1/2		
	61	S 32 E						
4+39			N 46 1/4 W	S 36 3/4 E		9 1/2		
	139^{7}	S 41 1/2 E					140	+7
$2+99^{3}$			N 44 W	S 49 1/2 E	5 1/2			
	89^{6}	S 36 E					90	+9
$2+09^{7}$			N 32 3/4 W	S 35 1/4 E	2 1/2			
	109^{7}	S 33 1/2 E					110	+8
1+00			N 38 1/2 W	S 34 E		4 1/2		
	100	S 38 E						
0+00			N 38 W	S 38 E				
= 52 + 80 P.O.T. Rd. No. 23-8-11								
	180	S 38 E		S 3				
51+00	Sec. Line $\frac{11}{14}$ T. 23 S., R. 8 W. W. M.							

(These Three columns used for coord. computation)

These columns used only when dist. slope chained.

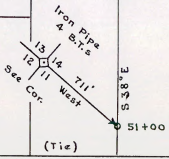
Date: 8-4-1960

Party: J. Doe C.O.P.
R. Roe
C. Poe H.C.

Instrument: K&E Compass
200' Tape

Weather: Fair & Warm

Sketches & Remarks



as the topographer sees them on the ground. On gentle slopes hand level and rod are used to get cross-section elevation points. Topography is taken by a three-man party--Abneyman, chainman and topographer.

522.5 TRIAL PAPER LOCATION. The field topography is traced on to the hardshell with carbon paper. Control points are selected and a grade contour stepped off along the contours in a manner similar to that described in Section 411. Optimum center line points are ticked, taking into consideration the desired cut for the side slope, or the fill over culverts. A trial L-line is drawn by lining tangents through these points and fitting the tangents with curves, using plastic curve templets. (Fig. 411-2)

522.6 TRIAL PROFILE. Stations are stepped off along the trial L-line with dividers and elevations read off by interpolation by eye. Anyone accustomed to reading a slide rule can estimate fifths of the distance between contours and read elevations to the nearest foot. A trial profile is plotted and a grade line fitted. If balanced quantities are desired, cross-sections can be read off and earthwork volumes computed.

522.7 PAPER LOCATION REVISION. The L-line on the plan is revised as indicated by the trial profile and quantities. A profile of the revised portions is plotted to check whether the revision is satisfactory. This process of trial and revision is repeated until the engineer is satisfied that he has the best location. The tangent bearings are measured with the drafting machine, and the distances between PIs scaled. Curve data and L-line stationing is computed. Stations are plotted. Ties to key points on the L-line from convenient points on the P-line are scaled. The best method of setting a key point on the L-line is by taping the distances from two stakes on the P-line, equivalent to swinging two arc with a compass to intersect a point. Key points include PIs, POTs and PCs and PTs of long curves. A pencil tracing of the L-line, P-line and ties is made to take into the field.

522.8 FIELD LOCATION. Key points are set by making simultaneous measurements with tapes on reels from two P-line stakes. Station and +50 stakes between the key points are set by chaining and lining by eye. Use of two range poles is helpful in this operation. A three-man party consisting of chief of party and two chainmen is used for location. Brush is swamped between stakes sufficient for the level party to follow the L-line. Leveling is done by engineer's level and rod. Slope stakes are set and the L-line referenced. If the L-line is not to be staked until after clearing and grubbing has been done, clearing stakes are set and referenced from the P-line. Any accumulated discrepancies between distances scaled on the hardshell and chained on the ground are taken care of by equations at intervals. Large discrepancies indicate errors in either P-line or L-line computations or scaling and should be checked.

530 CLASS "B" SURVEYS

531 CONTOUR OFFSET LOCATION

531.1 CONTOUR OFFSET METHOD.

1. Preliminary. The preliminary line (P-line) is the control for the contour offset method and the location line (L-line) is designed by computations based on the P-line. The P-line is a compass and tape traverse, with elevations at all stakes obtained by Abney or hand levels. Abney side slopes are taken at all elevations points. The road design may be done either in the office or the field.

2. Office design. If the design is done in the office, the profile of the P-line is plotted and a grade line fitted. Offsets from the P-line to the grade contour are computed or obtained graphically. The plan of the traverse and the grade contour by offsets is plotted. Optimum center line points are plotted, and the tangents and curves for the L-line fitted to them. Offsets from P-line to L-line are scaled. The center line cut or fill is computed. Detailed instructions for design are given in Section 711.

3. Field design. In the field design, the desired grade elevations are carried in the field notes, and Abney leveling is done concurrently with the traversing. Offsets to the grade line and to the L-line center line and L-line cuts and fills are computed.

4. Conditions to which adapted. The contour offset location is a more rapid and economical method, especially in office work, than the Class "A" survey methods. It is best adapted to relatively smooth side slopes, broken only by rounded ridges and shallow valleys. It is less suitable for use in rough, broken terrain with sharp ridges and narrow valleys or where heavy cuts and fills are involved.

5. Staking methods. Two methods of staking the P-line are used. Where the L-line is to be staked, stakes are set on the P-line at station and +50 points as well as at angle points. The station and +50 stakes are offset to the L-line. If the L-line center line is not to be staked, or if staking is deferred until after clearing and grubbing, stakes are set only at angle points and at intermediate points at significant grade breaks between them. In order to get a good profile stakes should average not more than 75 feet apart.

6. Leveling. Leveling may be done concurrently with the traversing by single Abney or double Abney. The latter is preferable if the line is being run at or close to the maximum permissable grade for the road standard. If leveling is by hand level and rod it is done as a separate operation.

7. Templet cross-sections. Where difficult problems in the design of alignment are encountered, the side slopes may be plotted on 10 x 10 cross-section paper and a road templet used to determine the cut or fill, and the position of the L-line with respect to the P-line. This system is also used where balanced quantities are desired.

8. Detailed procedures. Detailed instructions for surveying P-line traverse are given in Articles 531.2 and 531.3. Tested procedures

for the most efficient operation of the survey party are emphasized. An efficiently operating party has all the members continuously constructively occupied. No one is idle waiting on the others. Systematic checks are made to detect mistakes. Since the L-line is not independently traversed or leveled it is essential that there be no errors in the P-line.

531.2 PARTY ORGANIZATION.

1. Three-man party. Following is the organization for a three-man P-line traverse party when swamping and traversing are done concurrently, as where brush is light:

JOB	EQUIPMENT	DUTIES
Chief-of-party	Range pole Abney level Hand compass Flagging tape Kiel, axe	Selects Angle points Head chains Swamps
Compassman	Staff compass Abney level Field book, Form 301 Pencils Calders' slope tables	Runs compass Rear chains on occasion Shoots side slopes Keeps notes
Chainman	200' steel tape Stakes Kiel Axe	Head chains or rear chains as occasion demands Cuts high poles for backsights Swamps

Additional equipment for certain conditions: 2 flash lights (on dark days or in dense cover) Abney level for chainmen (for double-Abney levels), right-angle prism for compassman.

If brush is heavy the more efficient procedure is to do the swamping and the traversing as two separate operations. The chief-of-party sets flagged high poles at angle points he selects. The other two men swamp the line between high poles. Usually the line will be swamped well ahead before beginning traversing.

2. Two-man party. Swamping and traversing are done as separate operations. The chief-of-party sets flagged high poles at angle points and swamps back. The compassman sets intermediate stakes at breaks in grade and swamps ahead. For traversing the chief-of-party carries a 200-foot tape, head chains and takes side slopes. The compassman runs compass, rear chains, reads the slope along the chained line, and keeps notes.

531.3 PRELIMINARY LINE TRAVERSE.

1. Selecting angle points. The P-line follows the tag line as closely as possible without sacrificing time by heavy swamping or short shots. Angle points are selected by the chief-of-party where the line of sight misses trees, swamping is light, and where the compassman can set his compass staff and have standing room. The longer the courses the fewer the bearings to read and the points to plot. However, these savings may be nullified by time wasted by the compassman in trying to see the high poles and to line intermediate stakes on too long a course. The chief-of-party must consider the sight ahead, as well as back, from the H.I. of the compass and not from his eye height. The selection of angle points requires good judgment on the part of the chief-of-party to keep within 20 feet of the estimated position of the L-line as well as to save surveying time.

2. Traversing. The compassman sets up on an angle point, records its station, and reads and records the back bearing to the highpole set on the previous A.P., and notes or sketches on the right-hand page any feature along the previous course which would affect the location. He checks the back bearing against the previous forward bearing. If there is a discrepancy which cannot be accounted for by local attraction, the bearings are re-read. If the line has not been previously swamped, the chief-of-party carries a range pole ahead, sets it on the next A.P. selected, and swamps out around it so there will be no brush to whip and jar the compass. He then swamps back along the line. The chainman swamps forward. Only enough swamping is done to sight between A.Ps. and to permit the tape to be pulled straight. As soon as the compassman can see the range pole, through his compass sights, the chainman can start head-chaining, with the compassman rear chaining up to the length of the tape, while the chief-of-party continues swamping. Beyond the tape length the chief-of-party head chains and the chainman rear chains. The compassman reads and records the forward bearing, and lines each stake as it is set by voice or arm signals. When within a tape length of the next A.P. the chief-of-party calls "Come ahead" to the compassman and lines the remaining stakes by eye. At the A.P. a stake is set in place of the range pole and the stationing marked on it. The compassman replaces his jacob staff with a previously cut high pole and proceeds ahead, noting the stationing in his field book. It is often desirable for the rear chainman to keep separate notes of distance and stationing also.

3. Leveling and slope shots. If Abney leveling is to be done concurrently with the traverse, the chainman returns to the first stake beyond the last A.P. to assist the compassman in leveling. Otherwise, he starts swamping ahead on the next course. The compassman takes an Abney reading on the side slopes at each stake and records the station and slopes. He checks to ensure that no stations are duplicated or omitted. Abney readings are taken perpendicular to the line on both sides. If brush does not interfere, he kneels down and sights parallel to the slope. Otherwise, he sights on his estimated eye height on a tree. If there is a break in slope within the anticipated limits of construction, he paces out to the break and reads the slope beyond. The slopes are recorded as a fraction, with the slope percent as the numerator and the distance out as the denominator. At A.Ps. the slope is taken in line with the bisector of the interior angle. If the line has been swamped as a separate operation, the rear chainman assists the compassman in taking side slopes.

Road design from the preliminary is covered in Chapter 710.

FIGURE 531-1 P-LINE FIELD NOTE FORM
For Contour Offset Road Location

Sta.	Back Brg.	Fwd. Brg.	Abney	Diff. Elev.	Elev.	Side Slope % L	R
24					724.0	-40	+40
		East	+3	+1.5			
△ +50					22.5	-50	+52
	N84W		+11	+5.5			
23					17.0	-55	+50
			+8 3/4	+4.4			
+50					12.6	-42	+40
		S84E	+7 1/4	+3.6			
△ 22					09.0	-35	+20/15 +30/20
	S53 ½W		+3	+1.5			
+50					07.5	-34	+30
			+1	+0.5			
21					07.0	-40	+40
		N53 ½E	+1	+0.5			
△ +50					06.5	-35	+35
	S53 ¼W		+5 1/4	+2.6			
20					703.9	-40/20 -30/20	+38
			+10	+5.0			
+50					698.9	-27	+33
		N53 ½E	+9 3/4	+4.0			
△ +09					94.9	-25	+28
	S62 ½W						
19					694.0	-22	+26

For field design add columns for "Grade %","Grade Elev.", P-Line "C" and "F" and "Contour Offset" to right-hand page. See Fig. 713-1 for Design Form using above field notes.

FIGURE 532-1 DIRECT LOCATION SAMPLE FIELD NOTE FORM

Page 7	Road	No. 23-8-11				Side Slope					Date: 8-12-60 Party: J. Doe C.O.P.
Sta.	Point	Bk. Brg.	Fwd. Brg.	Curve Data	T.O.	L	R				R. Roe
+82	P.T.					-20	+17				C. Poe H.C.
+50					1.8						Insts.: K&E Compass 100' Tape
+22	P.I.										25' T.O. Tape Weather: Clr. & Warm
16		S 50 1/2° W	N26E	Δ = 24 1/2'	2.8	+23	+23				
+60	P.C. 20° L			D = 20°							
+50				ST = 62' L = 122'							
+03	P.T.				M.O.	-26	+24				
15					TO 0.1 MO 0.9						
+74	P.I.	S 70° E	N 50 E	Δ = 120°		PI not Sct. 0° cor. from LC = 142' N 10° W					
+50				D = 70°	MO 14.8						
14				ST = 142'	14.8	Ridge Crest 14+17 -14	+13/11	+36/28			
+50				L = 171'	AO 5.4 TO 2.0						
+32	PC 70° R					-36	+34				
13					Defl. Brg.						Def'l L
+82	P.T.				N 20° N	-40	+36				50°
+50					N 11 1/4° W						41 1/4°
+24	P.I.	S 30° W	N 70° W	Δ = 100°							
12				D = 55°	N 2 1/2° E	5' Wide					27 1/2°
+50				ST = 124°	N 16 1/4° E	← S 70° W 11+90 -15 Cr. +15					13 3/4°
11	P.C. 55° L			L = 182'		-33	+25				
+50											
10	P.O.T.		N 30° E								

532 DIRECT LOCATION

532.1 DIRECT LOCATION METHOD. In the "Direct Location" method the L-line is run direct the field without first running a P-line. A good reconnaissance tag line to follow is essential. The tag line is used to line the tangents to PIs in the same manner as the grade contour is used in route projection on the map. The position of the PI is chosen, the degree of curve which best fits the conditions is determined, and the curve is staked on the ground. Where the L-line is to be staked before clearing and grubbing, direct location is the most time-saving method. It is adapted to relatively smooth, moderately broken, or rolling topography, where the best fit of the alignment to the ground is fairly apparent. The success of the "Direct Location" method depends upon the good judgment of the chief-of-party in selecting PIs and degree of curves.

The standard field note form for direct location, and sample notes are shown in Figure 532-1. Detailed procedures are given in Articles 532.3 to 532.9. Levels are run as a separate operation by a two-man party. Generally, leveling is by hand level and rod. If located to the maximum permissable grade of the road standard, use of the engineer's level is advisable. After the grade line is drawn on the profile some revisions may be indicated. However, the total time for original location and revision is less than the time required to run separate P-line and L-line. Abney side slopes for guidance in fitting the grade line to the profile may be taken either during location or leveling; side slopes are taken at intervals whenever the slope appears to change.

532.2 PARTY ORGANIZATION. Following is the organization for a three-man direct location party:

JOB	EQUIPMENT	DUTIES
Chief-of-party	Abney level Hand compass Flagging tape Kiel Axe	Selects PIs Sets high poles Decides degree of curve Head chains Swamps
Compassman	Staff compass Abney level 25' T.O. tape 5" Slide rule Field book, Form 301 Pencils Calders' "Forest Road Engineering Tables"	Runs compass Computes curve data Keeps notes May rear chain up to 100 feet
Chainman	100' Steel tape Cedar stakes Kiel Axe	Rear chains Marks curve Stakes Swamps

Additional equipment for certain conditions: 2 flash lights (on dark days), Range pole (where tangents are long), Abney level for chainman (for double-Abney levels).

532.3 SELECTING POINTS OF INTERSECTION. The chief-of-party lines up several tags which make a straight line and proceeds along this tangent, past where the tags curve away from the tangent, to a point in line with the tags which outline the next tangent ahead; or he "backs in" the forward tangent to the intersection with the back tangent. At this PI he sets a "high-pole", and clears around it so it can be readily seen. In brushy cover it is preferable to swamp the tangents well ahead of the survey. The other two members of the party swamp the line between two successive high-poles while the chief-of-party is selecting the next PI. For safety each man swamps away from a PI toward the other man. If the swamping required is light, the chief-of-party swamps the tangent ahead while the others are chaining the back tangent. PIs should be set so that the line of sight between them misses intervening trees, as well as in the best positions for fitting the curves to the ground. If the PI is not conveniently accessible, as when crossing narrow ridges or valleys with a large intersection angle, "semi-PIs" or "double PIs" or the long chord may be used. On a long tangent P.O.T. high-poles are set at grade breaks, or run perpendicular from P.C. and P.T. and "swing" the curve using the tape like a drawing compass.

532.4 LOCATION TRAVERSE. The chief-of-party and chainman chain up from the last P.T. to the next PI, setting cedar stakes at station and +50 points. The chief-of-party marks the stakes as they are set. The compassman keeps them on line. When within a station of the next P.I. the chief-of-party signals "Come ahead" (the compassman never picks up his compass until signaled to come ahead by the chief-of-party).

The compassman sets up his compass on the PI, backsights to the last PI, and while waiting for the compass needle to settle enters the PI station in his field book, leaving ample space for PC and stations on the curve. He reads and records the back bearing, and then reads and records the forward bearing to the next PI. If the high-poles are not visible to the compassman, the other two men give him sights with flash lights at the high-poles. The compassman computes the Δ from the difference in bearings, and looks up the ST and EX for 1 degree curve in Calders' Table II.

The chief-of-party decides on the degree of curve, either (1) from the external to the tag line on the curve, (2) from the distance from the last PT, or (3) from the maximum permissable degree of curve for the road standard. The compassman computes and records the ST and L and the stationing of PC and PT. The data necessary for setting stakes on the curve, by the method decided upon by the chief-of-party, is also entered in the field book. The chainman marks the PC and PT stakes and the stakes for the last half of the curve before leaving the PI. The stakes already set on the ST while chaining up to the PI are offset to the first half of the curve.

532.5 STAKING CURVES. In the direct location method the center line along the curve is usually completely staked by setting station and +50 stakes on the curve for profile levels. On sharp curves, over 40 degrees, +25 stakes are set. The PC and PT stakes are usually set, although some engineers omit them. However, they show the PC and PT stations in the notes. The Tangent Offset Method of staking curves is the fastest and sufficiently precise when TOs do not exceed about 25 feet. The Middle Ordinate Method or the Chord Offset Method, or combinations of the two, are the faster for long, sharp curves, or when the PI is inaccessible. The Deflection Bearing Method is the slower but more precise method under conditions unsuitable for the use of the Tangent Offset Method.

The final step in curve location is to swamp the curve so that the stakes are intervisible. The chief-of-party and chainman then chain from the PT of the curve just set to the next PI, where the curve is computed and staked. Horizontal chaining by 50 foot increments may be done on grades up to 10 percent, and by 100 foot increments on grades up to 5 percent. On steeper grades, add the chainage correction from the percent exsecant table, (Fig. 512-1), or from Calders' Table I, and slope chain, taking care to hold both ends of the tape at the same height above the ground.

Example: To set a stake at 50 feet on 21% grade up a sharp ridge. From Table 1 horizontal distance for 50 feet. Slope distance on 21% grade = 48.9 feet. Difference 1.1 feet. Chain 51.1 feet. To set a stake at 100 feet on 10% grade. From Table 1 horizontal distance for 100 feet slope distance 99.5 Difference 0.5 feet. Chain 100.5 feet.

532.6 TANGENT OFFSET METHOD. Following is the procedure for staking the curve by the Tangent Offset Method. The chief-of-party and chainman set the PC stake by chaining from the nearest stake on the tangent or ST. The chainman remains at the PC and the chief-of-party pulls the 100 foot tape out the correct chord distance (given him by the compassman from Calders' Table 8) to the first station or +50 on the curve. The compassman leaves his compass at the PI, walks back along the ST until he is at a point from which the chief-of-party is perpendicular to the ST, obtained by extending his arms in line with the tangent and swinging his palms together until his fingers point at the chief-of-party. The compassman holds the tangent offset tape on the ST line at the tangent offset distance (from Calders' Table 7) and hands the stake for the point on the curve, originally set on the ST, and the zero end of the tangent offset tape, to the chief-of-party. The chief-of-party grasps the 100 foot tape and the tangent offset tape, pulls them taut simultaneously and drops the stake at the intersection of the zero marks of the two tapes. This procedure is repeated until all the stakes on the ST have been offset to the curve. (When the stake 100 feet from the chainman has been set he moves up and rear chains from that stake.) The chief-of-party and chainman then chain out the ST distance and set the PT. The stakes on the second half of the curve are "backed in" from the PT, using the same procedure as above except that the chief-of-party carries with him the previously marked curve stakes.

As a check on the accuracy of the computations and chaining, measure the distance between the last stake set on the first half of the curve and the last stake set on the second half of the curve. If this does not check with the chord for a 50' arc within 1 foot, it indicates an error in computation, reading the tables, or chainage. Error in computing the intersection angle is indicated by a large discrepancy between the chord and the measured distance.

532.7 DEFLECTION BEARING METHOD. To stake a curve by the Deflection Bearing Method the compassman sets up his compass on the PC (or PT) turns to the successive deflection bearings and lines the stakes. He also rear chains for stakes up to 100 feet away. (Deflection angle= ½ angle subtended by distance on curve. Deflection angle for 50 feet = ¼ degree of curve; for 100 feet = ½ degree of curve; for any other distance = 0.3 minute per foot per degree of curve. The deflection angle is added to or subtracted from the tangent bearing, depending upon the quadrant and curve direction, to obtain deflection bearing.) If lack of visibility necessitates setting up on a POC, he applies to the bearing to the POC the total deflection angle turned to the POC. This gives the bearing of a tangent to the curve at the POC. With the POC at a station or +50, applying the deflection angle for each 50 feet to the tangent bearing gives the deflection bearings to turn to set further stakes on the curve. Comparison of the bearing read to the previously established PT (or PC) from the last station occupied with the computed bearing, and the distance from the last stake set, gives a check on the accuracy of the work. If the error is appreciable, but the computations check, run the second half of the curve back, throwing any error into the middle of the curve. This procedure is repeated until the last stake on the curve is reached. Measurement of the distance from the last stake to the ST, compared with its tangent offset, and to the PT, gives a check on the accuracy of computations, lining, and chaining. If the error indicates the desirability of doing so, the second half of the curve is restaked back from the PT.

532.8 MIDDLE ORDINATE METHOD. To stake a curve by the Middle Ordinate Method, the first stake on the curve is set by the tangent offset. If the PC is not on a station or +50, the Short Ordinate for the arc distance to the first stake is taken from Calders' Table 9, and measured in the estimated direction of the radius (perpendicular to the chord from PC to first station or +50 points). A temporary MO stake or range pole is set at the short ordinate distance. The chief-of-party puts himself on line with the PC and the MO stake and chains the chord distance from the PC and sets the second curve stake. The chainman checks that the first curve stake is perpendicular to the chord from the MO stake, and adjusts it along the chord if necessary. The chief-of-party re-lines the second curve stake with the MO and PC stakes. The MO for 100 foot arc is then measured along the estimated radius, the chord for 100 foot arch chained from the first curve stake, the third stake set, and the alignment check made.

532.9 CHORD OFFSET METHOD. The Chord Offset Method is a useful alternative to the Middle Ordinate Method when the MO line of sight is obscured by trees. The chord is extended by setting a blank stake at the chord distance for 50 foot arc in line with the previous two stakes in the curve. The chord offset equals twice the tangent offset for the distance (CO = 2 TO). Simultaneous measurement of the chord distance from the previous stake and the CO from the blank stake, will establish the new point on the curve. The chord offset requires a longer offset measurement and usually more swamping than the middle ordinate method.

540 PROFILE LEVELS

541 CLASS "A" SURVEY LEVELS

541.1 ENGINEER'S LEVEL AND ROD.

1. The engineer's level and rod is used in class "A" road surveys to obtain elevations at staked points. The engineer's level is also used on class "B" surveys where elevations are carried for long distances without checking in on a bench mark established with engineer's level. Bench marks should be established outside the limits of construction at intervals of approximately 1000 feet. Bench marks should also be set in the vicinity of bridge sites and high fills. The basic principle in making a bench mark is to leave no doubt as to where the rod was held when the elevation was established. The permanence of the bench mark is a consideration. The preferred type of forest bench mark is chopped on the root swell of a thin barked species of tree just above the ground. A notch is chopped leaving a high point in which a nail is driven. Bench marks are numbered consecutively and the number and elevation marked on a blaze above the notch. The bench mark and its location should be completely described in the field notes.

2. Detailed instructions for operation of the level and rod are given in every plane surveying text book. The following level note form is recommended instead of the usual text book note form:

Sta	+S	HI	-S	IFS	Elev.

Fore sight rod readings, read to 0.01 foot, on turning points are entered in the "-S" column. Rod readings, read to 0.1 foot, on intermediate stations are entered in the "IFS" (intermediate fore sight) column. IFS elevations are not computed until after the turning point elevations have been checked by the difference between the sums of "+S" and "-S" columns.

Station elevations should be taken on plugs or small hubs driven flush with the ground in front of each stake, as close to the stake as possible. Many of these plugs will survive clearing and grubbing, even though the stakes are gone, and are invaluable in re-staking the line. If a break in the profile, such as a ridge crest or creek bottom occurs which has not been staked, the elevation should be taken, and the station obtained by measuring from the nearest stake with the level rod.

3. In leveling across canyons time can be saved by taking a turning point across the canyon and running a hand level line down to the bottom and up the other side, closing on the turning point previously set with engineer's level. Draw lines across the page to isolate the hand level notes from the other notes. The levelman should carry a hand level to ensure that he does not set up his engineer's level too low or too high to see the rod.

542 CLASS "B" SURVEY LEVELS

542.1 HAND LEVEL AND ROD. Leveling with the hand level and rod is faster than with the engineer's level, but less precise, as rod readings on turning points can only be taken to 0.1 foot. On long lines of levels errors tend to accumulate. Home-made cedar hand level rods 15 feet long with feet and tenths only marked, are often used for hand levels instead of the conventional rod. The best practice in using the hand level is to rest it on a pole cut to the levelman's eye height. One end of the pole is sharpened so it can be jabbed in the ground and thus eliminate errors due to the HI shifting. Rod readings too far away to see the tenth marks clearly can be taken by the rodman holding a red tag against the rod and sliding it up or down as directed by the levelman, until the cross-hair intercepts the top of the tag. The rodman calls off the reading.

The same form of level notes is used as given in Article 541.1(2). Bench marks should be set as in Article 541.1(1) for use during construction.

542.2 DOUBLE ABNEY LEVELS. Double-Abney levels for class "B" surveys made by the following procedure are more precise and afford less chance for error than single-Abney levels. Two square end poles are cut equal to the HI of the shorter man. The class "B" line is usually leveled by the compassman and chainman. The compassman, who keeps the notes, occupies the rear station, rests his Abney on the pole placed on the plug alongside the stake, previously driven by the chainman. The chainman places his pole and Abney on the forward station. The two men take simultaneous sights, using the other's Abney as the sighting mark. The compassman reads his Abney and calls out the algabraic sign and reading, as "plus 8" or "minus 6". The chainman reads his Abney and calls "check" if he agrees. He calls "No" if his Abney reading differs more than ¼ percent and "Wrong" if the compassman calls the wrong sign. If the readings do not agree they are repeated and checked. As soon as the reading is checked the compassman enters it in his field book on a line <u>between the two stations</u>, so there can be no doubt to any other user of the field notes as to what the entry applies. Under no circumstances does the chainman call out his Abney readings or sign, since this may lead to confusion and the wrong entry in the field book. It helps the chainman to check the sign if plus and minus signs are marked on his Abney opposite to the plus and minus direction on the compassman's Abney arc.

The Salem district recommends that when double-Abney leveling is done concurrent with traversing, the chainman keeps a separate set of chaining and Abney notes. He records the sign he reads back, opposite to the sign the compassman reads forward. At breaks during the day, as at lunch time, the two sets of notes are compared. The chainman calls out his reading first, so as not to be influenced by the more experienced compassman. The compassman then calls out his reading.

Double-Abney levels of less precision are taken without the use of HI poles by sighting at the point of the observer's HI on the chainman. Single-Abney levels are taken by the compassman sighting on his HI on the chainman, or on a red tag in a slit in the top of a pole at his HI held by the chainman. There is no check on a single-Abney shot except to repeat it. If plugs are not driven, or HI poles are not used, the compassman must take care to stand in the same place as the compassman stood when occupying the station. On steep side slopes the compassman should trample a cleared flat spot to stand on next to the stake.

550 CROSS SECTIONING

551 CROSS SECTIONING FOR TOPOGRAPHY

551.1 PEGGING CONTOURS WITH HAND LEVEL AND ROD. The highway engineer's method of pegging contours with hand level and rod, while not commonly used for side-hill forest roads, is useful for bridge site surveys, for taking topography along flat valley bottoms, and for ridge and valley crossings involving heavy cuts and fill where balanced sections are desired. Cross-sections are taken on both sides of the P-line as far out as the possible limits of construction.

1. The work is facilitated by resting the hand level on a pole with squared ends of such length that the cross-hair of the hand level resting on the pole will be 5 feet above the bottom of the pole. The levelman sets the pole on the station. The HI elevation is then equal to the station elevation plus 5 feet. The rod man swings a perpendicular, picks a line tree or mark and carries the rod out along that line until, by trial a point is found where the rod reading equals the difference between the HI elevation and the contour elevation. The horizontal distance to the rod is measured with a steel or cloth tape on a reel. The contour and the distance to it is entered as a fraction in the notes, the numerator being the contour and the denominator the distance out from the station stake. With a two-man party the levelman keeps notes.

Example: Station elevation 702.5, HI 707.5. Rod reading for 700 ft. contour 7.5; for 705 contour 2.5.

2. The rodman holds his point and the levelman takes the head end of the tape and goes ahead until he reaches a point where, with his hand level on the pole, he reads 10 ft. on the road going uphill, or the bottom of the rod going downhill. He is now on the next 5 ft. contour. The horizontal distance from rod to pole is measured and added to the previous distance from stake to rod to get the denominator of the cross-section fraction. The levelman holds his point, they exchange ends of the tape, and the rodman goes ahead until the levelman reads the bottom of the rod uphill, or 10 ft. on the rod downhill. The rodman is now on the next 5 ft. contour. This procedure is repeated, with levelman and rodman alternating, until a sufficient number of contours have been pegged. With a 15 ft. rod the levelman can peg two contours in succession without the rodman changing position when proceeding uphill, or the levelman downhill.

3. A more accurate map is obtained if contours are drawn in the field, rather than in the office. For field mapping a topographer is added to the party. On a tracing or pricked hard copy of the traverse plan held in a Tatum holder, he plots the contour points on the perpendicular lines and draws the contours as he sees them for 50 ft. each side of the line. It

is desirable to note the successive distances on the edge of the map strip in line with the cross-section. On a tracing he uses a 6 inch 10-50 flat scale to plot contour points. On 10 x 10 cross-section paper he plots by eye. In this case cross-sections are taken in cardinal direction lines by hand or staff compass carried by the topographer. He also takes compass bearings of creeks and ridge crests and other topographic features.

4. If contours are to be drawn in the office, the levelman notes topographic features on the right-hand page of the field book, and sketches form lines if the contours do not run straight between pegged points. If a 5 ft. contour crosses the line between two successive station stakes, the contour is located as the party proceeds toward the next station.

551.2 ABNEY AND SLOPE CHAINING FOR TOPOGRAPHY. An Abney level and slope-chained line is run out from the station stake, with elevations being taken at breaks in cross-section and at other points sufficient to enable the topographer to interpolate the contours. These elevation points are plotted by the topographer on the tracing or hard copy of the P-line traverse (Article 522.3). The 5 ft. contours points are interpolated, and the contours drawn for 50 ft. each side of the cross-section line at each station. Horizontal distance between contours is obtained from the percent cotangent table. Calders' Abney Table 1 is used to convert Abney reading and slope distance to difference in elevation and horizontal distance. Taking elevation points at even 10 ft. slope distances will save time in using the Abney tables. The topographer uses a compass to get directions of creeks and ridge crests, which are plotted before contours are drawn. Use a dotted line for ridge crest direction.

552 CROSS SECTIONING FOR SLOPE STAKES

552.1 SETTING SLOPE STAKES WITH HAND LEVEL AND ROD. The conventional highway engineer's method of setting slope stakes with hand level and rod is given in detail in route survey or highway engineering text books, so is referred to only briefly here. The slope stake point is found by trial at the point where the horizontal distance out from the center line equals the half-base of the road sub-grade plus the difference in elevation times the bank slope ratio. As the method requires pegging up with differential levels on slopes over about 30 percent, it is little used on forest roads on steep slopes. It is suitable for gentle slopes, such as river valley bottoms, and for approach fills to bridges.

A hand level, 50 ft. tape and 12 ft. level rod is conventionally used. Using homemade cedar rod 15 ft. long marked in feet and tenths will speed up the work. Such a rod is used to measure horizontal distances as well as differences in elevation. It can be pushed through the brush faster than a tape can be carried.

For the guidance of the grading crew, slope stakes are customarily set at the following points: At the top of the cut bank for excavations; at the toe of the fill slope for embankments; at the top of the cut bank on the upper side and the grade point on the lower side for "side-hill" or "cut-and-fill" sections. Upper slope stakes are referenced. The toe of the fill on side hill sections usually is not staked, although the point may be located and recorded for computing end areas. The coordinates at the slope stake points, referred to the finished grade elevation as a numerator, and to the center line as a denominator are recorded.

552.2 SETTING SLOPE STAKES WITH ABNEY AND SLOPE -CHAINING. The fastest method of setting slope stakes, on slopes over 30 percent, is to use the Abney and slope chaining and Calders' Tables 13 to 16. The chainman goes out perpendicular to the center line to the estimated approximate distance to the slope stake point. The levelman reads the slope percent of a sight on the chainman. He finds in the appropriate table the slope distance (50) for the center line cut or fill and the correction for R.B. other than 22 ft. and holds the distance on the tape at the station stake. The chainman pulls the tape taut, and at the same height above the ground, and sets a stake. The levelman takes a check Abney reading on the slope to the slope stake point. If the slope has changed, he corrects the slope distance.

The levelman computes the slope stake fraction, enters it in the notes, and calls it out to the the chainman who marks it on the front of the stake. The station is marked on the back of the stake. The horizontal distance to a slope stake at the top of an excavation section computed from the data given in Calders' tables by the formula:

$$HD = \frac{1}{2} \text{ base} + (SC \times CS)$$

Where HD is horizontal distance, SC is side cut or difference in elevation between sub-grade and slope stake point, and CS is cut slope as ½, 3/4 or 1 to 1.

Since Calders' tables are for a half-base of 11 ft., (22 ft. R.B.), and the minimum half-base on a Bureau of Land Management Class III road on a tangent is 13 ft. (26 ft. R.B.), a "correcting factor" taken from the 26 ft. line below the table must be added to the SD and SC . The formula then becomes: HD = 13 + (SC + correcting factor) x CS. On the inside of a curve, the half base must be increased by 400/radius or 0.07 x degree of curve.

Example:

	Cut	SD	SC	Cut	SD	SC
CS		1:1			3/4:1	
GS		54%			56%	
22' RB :	5.5	40.8	24.9	5.5	29.9	20.1
+ correction to 26' RB:		4.9	2.3		4.0	2.0
26' RB :		45.7	27.2		33.9	22.1
SC			x 1			x 3/4
(SC x CS)			27.2			16.6
half base			13.0			13.0
HD			40.2			29.6
Slope stake fraction:			+27.2 / 40.2			+22.1 / 29.6

FIGURE 552-1 SLOPE STAKE CROSS-SECTION NOTE FORM
For Abney and Slope Chaining, using Calders' Tables

Sta	Ground Elev.	Grade Elev.	C	F	Slope % L	Slope % R	Half-Base	C/S Notes L	C/S Notes ℄	C/S Notes R	Off-Set 10'
20	700.0	700.0	0.	0		+30	11/13	−6.0 / 20.0	0 / 0	+5.6 / 18.6	+8.6 / 28.6
+50	04.1	03.0	1.1			+35	13	0 / 2.9	+1.1 / 0	+8.5 / 21.5	+12.0 / 31.5
21	06.6	06.0	0.6			+40	13	0 / 1.5	+0.6 / 0	+9.6 / 22.6	13.6 / 32.6
+17 PC 20° R											
+52	09.8	09.1	0.7			+30	14.4	0 / 2.3	+0.7 / 0	+7.2 / 21.6	10.2 / 31.6
+96	13.5	11.7	1.8			+30	14.4	0 / 6.0	+1.8 / 0	+8.8 / 23.2	+11.8 / 33.2
22 +39	15.9	14.3	1.6			+40	14.4	0 / 4.0	+1.6 / 0	+12.2 / 26.6	+15.2 / 36.6
22 + 67 BK = 22 + 78 Ah. PT 16.0											
23	18.9	17.4	1.5			+50	13	0 / 3.0	+1.5 / 0	+16.0 / 29.0	+21.0 / 39.0
+50	22.5	20.7	1.8			+52	13	0 / 3.5	+1.8 / 0	+17.8 / 30.8	+23.0 / 40.8
24	24.0	24.0	0.	0	−40	+40	11/13	−15.0 −11.0	0 / 0	+ 8.6 / 21.6	+12.6 / 31.6
+50	21.0	27.0		6.0	−30	+30	11	−19.9 / 46.3 | −16.9 / 36.3	−6.0 / 0	− 1.8 / 13.7	+ 1.2 / 23.7

Material: Common
Cut Slope 1:1
Fill Slope $1\frac{1}{2}$:1

HD may also be computed by applying the percent versine table to SD.

Example: For 54% slope, "ver. x 100" = 12.0
SD of 45.7 x .120 = 5.5
HD = 45.7 - 5.5 = 40.2

Horizontal distance to a fill slope stake at the toe of an embankment is computed from the formula:

HD = half base + ($1\frac{1}{2}$ x (SF + correcting factor)

Where SF is "side fill," or difference in elevation between sub-grade and slope stake. The embankment half-base on tangents is a minimum of 10 ft. plus 1 ft. for fills up to 6 ft., and plus 2 ft. for fills over 6 ft. The half-base on the inside of the curve is also widened 0.07 x degree of curve.

Example: Fill 7.0 ft. on 40% slope on inside of 30 degree curve. Half-base then is 10' + 2' + (0.07 x 30) = 14.1 and RB = 28'. From Calders' Table 16, for 16' RB, SD = 49.8, SF = 25.5, correcting factors for 28' RB = 16.2 and 6.0. For 28' RB, SD = 49.8 + 16.2 = 66.0 and SF = 25.5 + 6.0 = 31.5.

HD = 14.1 + ($1\frac{1}{2}$ x 31.5) = 61.3 Slope stake fraction = $\frac{-31.5}{61.3}$

Or, from percent versine table, "vers. x 100" = 7.2 66.0 x .072 = 4.7
HD = 66.0 - 4.7 = 61.3

On side hill cut-and-fill sections, the grade point where cut changes to fill may be found from Calders' Table 17. This point should be found and entered in the field notes for use in computing end areas. The minus sign (-) in the numerator of the slope stake fraction means a fill. A positive sign (+) means a cut. Sample field notes are given in Figure 552-1.

552.3 OFFSETTING SLOPE STAKES. Slope stakes set prior to right-of-way clearing are offset back <u>from the clearing line</u> a horizontal distance of 5 feet. The clearing limit is 5 feet or 10 feet beyond the top of the cut bank, depending upon the size of the trees. Consequently the slope stakes are offset a uniform horizontal distance of either 10 feet or 15 feet. Two slope stake marking methods are used. If the slope stake is to be returned to the slope stake point at the top of the cut bank after the clearing and grubbing operation, the offset is marked on the stake, underneath the slope stake fraction, with a double line across the stake separating the two. The construction foreman is also informed of the uniform offset distance. If the staking of the top of the cut bank is to be left to the construction crew, the slope stake fraction marked on the stake is the coordinates of the offset point, i.e., the difference in elevation between the offset point and the finished grade and the distance from the center line to the offset point. This fraction is entered in the cross section notes with a vertical line separating it from the last cross-section fraction, so the offset fraction will not be included in the end area computation. This is shown in the sample field notes in Figure 552-1. For slope stake referencing, see Section 563. The clearing limit line is marked with Form A1-3 cards. Instructions for staking culverts are given in Article 833.1.

560 REFERENCING AND TIES

561 REFERENCING ALIGNMENT

561.1 NEED FOR REFERENCING. Any stake within clearing limits is liable to be displaced or destroyed during the various stages of construction. Consequently, stakes have to be replaced to guide the construction crew. Some stakes may be replaced several times. It is essential that road surveys be referenced, so that stakes can be re-set quickly and accurately. Referencing should be done soon after a line is staked, as stakes are knocked down by animals also.

561.2 INTENSITY OF REFERENCING. The intensity of referencing varies from referencing every stake to referencing only points of change in direction of tangents, such as PIs or APs. The intensity and the method of referencing used depends upon who is to do the restaking and their availability. If an engineering crew is available during construction, a minimum of referencing, by methods using the staff compass, is required. If re-staking is to be done by the construction crew, a maximum of referencing, by tape only, is desirable. The minimal referencing for class "B" surveys where slope stakes have not been set, follows:

1. P-line for contour offset location, reference all points occupied by the staff compass.

2. Direct-located L-line, reference all PIs; PCs and PTs of long curves, and POTs of long tangents.

561.3 CENTER LINE FROM SLOPE STAKES. Where slope stakes have been set, and properly offset or referenced so they can be re-set, the center line stakes may be restored by measuring the denominator of the slope stake fraction from the slope stake, in a direction perpendicular to the center line. The lateral position is checked by measuring the distance to the previous stake and adjusting forward or back. The hand compass may also be used on the line from slope stake to center line stake, by setting off a bearing 90 degrees from the known tangent bearing.

561.4 REFERENCING WITH STAFF COMPASS AND TAPE. The compassman sets up the staff compass on the point to be referenced and takes a bearing on a tree beyond the clearing limit on the upper side. The chainman drives a hub or a stake on line, also beyond the clearing limit. He chops a blaze on the tree and marks the intersection of the line with the blaze, either with a nail or a ⓧ with kiel. The distance from the reference point (RP) to the compass is measured. On steep slopes the Abney is used and the slope distance converted to horizontal distance. The letters RP, station of the point referenced, bearing and distance are marked on the blaze, or marked on a square of aluminum foil with a ball point pen, and nailed to the blaze. The compassman records the same data on the right-hand page of the traverse field book, together with the diameter and species of the reference tree.

The point is re-set by setting up the compass on the hub, back-sighting on the RP and setting a stake on the fore-sight of this line at the measured distance. If the hub is lost the compass is set up near the tree, by trial, until the bearing to the RP coincides with the original reference bearing.

561.5 REFERENCING WITH TAPE ONLY. Two methods of tape referencing are used. The first is a modification of the compass method (Article 561.4). The hub is set on line between the RP and the point being referenced, by eye, with the help of range poles. The point is re-established by lining the stake by eye with a range pole on the hub and the RP, and measuring the distance from the RP. On gentle slopes two reference trees, one on each side in line with the center line stake, may be used. Stretching the tape between trees and measuring one distance, re-establishes the stake point.

The second method involves the principal of fixing a point by the intersection of two arcs, as is done with a drawing compass. Two reference trees beyond the clearing limit are selected. They should preferably be at angles of between 45 degrees and 60 degrees with the center line. Each reference tree is blazed and an (X) marked on the blaze. The distance to each RP is measured and the station and distance marked on the blaze or on aluminum foil. The distances are recorded on a sketch on the right-hand page of the field notes. Sometimes a hand compass is used to get the angle between the RPs, or the distance between the two reference trees is measured, to aid in finding them a long time later. To restore the point referenced, the two distances are measured simultaneously with two tapes. If only one tape is available, a short arc can be scratched on the ground by swinging the tape held at one RP, and the intersection found by measuring from the other RP.

While slope distances can be used for restoring the original point on the ground after clearing and grubbing, it is preferable to use, or convert to, horizontal distances, so that the point can be restored during or after grading for checking alignment. The policy of designating reference measurements by horizontal distance is recommended.

In the ponderosa pine region where lath is used for staking, two laths are driven in line with point referenced, 10 or 15 feet apart, beyond the clearing limit. The station and the distance to the point from the nearer lath, is marked on that lath.

562 REFERENCING GRADE ELEVATION

562.1 GRADE ELEVATIONS FROM SLOPE STAKES. Where slope stakes have been set, the grade elevations may be checked, or the cut or fill still required to bring the subgrade to the grade elevation determined, by measuring, from the slope stake point, a difference in elevation equal to the numerator of the slope stake fraction. Difference in elevation may be measured by hand level and rod, or by Abney and slope chaining, converting to difference in elevation by Calders' Table 1.

562.2 REFERENCE TREES. The RP on a reference tree may also be used as a grade elevation reference. A narrow horizontal shelf is chopped at the bottom of the RP blaze. The difference in elevation between the shelf and the center line stake ground elevation is obtained, either with hand level and rod, or Abney and slope tape, using two HI poles. The cut or fill at the center line stake is added to or subtracted from the difference in elevation, and the cut or fill from RP shelf to sub grade marked on the blaze. If aluminum foil is used, the bottom of the square is used as the elevation reference. All data marked on the blaze and a description of the reference tree is recorded in the field notes.

Another method of referencing grade elevation, is to chop a narrow horizontal blaze, or nail a short stake or a strip of aluminum foil horizontally, at sub grade elevation on a tree on the edge of the lower right-of-way clearing limit. This method is useful when an engineer will not be available during construction, as one of the construction crew with a hand level can readily determine when grade elevation is reached. On steep slopes climbing irons or a light aluminum ladder are needed to enable the rodman to reach high enough on the reference tree. The levelman moves up or down from the center line stake until his hand level HI is at grade elevation. The rodman moves his axe head or a stake up the tree to the intersection of the level line and marks the line on the tree.

563 REFERENCING SLOPE STAKES

563.1 REFERENCE MARKS. If only infrequent engineering supervision of construction can be given, slope stakes should be referenced. Such referencing permits a better check to be made of adherence of construction to design specifications. A reference tree outside of the clearing limit, and, if possible, in line with the slope stake and the center line stake, is selected. The distance and bearing from the slope stake to the tree is measured. The station, distance, bearing, and the slope stake fraction is marked on a blaze on the tree, or on a stake or aluminum foil nailed to the tree. The latter is the faster method. Aluminum foil has the advantage of being more clearly visible from the center line, or from the grade when compliance of the construction with design is being checked.

564 TIES

564.1 CORNER TIES. Where a road survey line crosses a section line the survey should be tied to the nearest section corner or one-quarter corner. The tie line should be run from the corner in a straight line, off-setting past trees, to the road line. The bearing to run is determined from the available evidence of the bearing of the section line. The equation of the station on the section line which equals the station on the road survey line is marked on a stake at the point of intersection, and recorded in the field notes, together with an illustrative sketch and descriptions of the corner monuments. The tie line is run with staff compass and 200 ft. tape unless right-of-way problems necessitate a transit line tie.

Where a road survey line crosses a subdivision line, in a section which has been subdivided by survey, a tie line should be run from the nearest established corner to the road. In a section which has not been subdivided, if the road survey passes within about 20 chains of a one-quarter corner, a tie line should be run from the one-quarter corner, on the estimated bearing of the one-quarter line, to the road survey line.

564.2 OTHER TIES. The road survey line should be tied to any existing roads, structures and other points identifiable on the map or aerial photo. This will help to plot the road traverse more accurately, and to correct for accumulated errors in compass bearings. "Structures" might include bridges, buildings, and mining claim corner monuments. The tie should be recorded by bearing and distance from a survey station to the object tied, together with a sketch of the tie and a description of the object. In starting a survey from an existing road it is extremely important that a tie be made which will fix the position of the survey with reference to the existing road. It may be necessary to traverse a portion of the existing road to an identifiable station.

564.3 AERIAL PHOTO POINTS. It will be found to be exceedingly helpful to future planning or mapping if identifiable stations along the road survey line are pin-pricked on the aerial photos. Corners tied and section line intersections should also be pricked on the photos. If they are not identifiable, tie them to the nearest point identifiable on the photo and record the tie on the back of the photo as well as in the field notes. The station of a survey point pricked, or description of the corner, is recorded on the back of the photo. Cross-referencing of field notes and photos is important.

570 BRIDGE AND CULVERT SITE SURVEYS

571 BRIDGE SITE SURVEYS

571.1 WHEN REQUIRED. A special bridge site survey is required when a bridge is to be designed. While site surveys for permanent concrete or steel bridges are usually made by the Bureau of Public Roads, the Bureau of Land Management engineer may have occasion to make such surveys. To attain the maximum possible serviceability and life of timber bridges to be built by the logging operators, they should be designed by Bureau of Land Management engineers. Site surveys are essential as a basis for proper design. Instructions for making a bridge site survey are given in ensuing sections.

571.2 CENTER LINE TRAVERSE. The bridge site survey center line should be run as close to the final center line of the bridge and its approaches as can be determined on the ground. Traverse the center line with transit and steel tape. Set stakes every 20 feet, and at all breaks in the profile of the line. Extend the line far enough to include approach fills, otherwise a minimum of 100 feet from each end of the bridge. Chain carefully with plumb bobs to tacks in hubs. If the water course is too wide to measure with the longest tape available, or the current is too strong to handle the tape, obtain the width by triangulation with the transit. Starting from a center line tack on one bank, lay off a baseline along the bank approximately equal in length to the estimated width of the river. Turn the interior angles at each end of the baseline, by repetition, to a tack in a hub on the center line on the other bank. If it is feasible for the transitman to occupy the point on the other bank, turn the third angle. Calculate the distance between the two center line tacks by solving the oblique triangle by the sine law. Reference the center line transit points by the method given in Article 561.4, except that the transit is used instead of the compass, with angles being turned from the center line instead of bearings, and a "butterfly" backsight nail set for a sight on the reference point.

571.3 CENTER LINE LEVELS. Obtain profile elevations on plugs at all stakes with engineer's level and rod. "Double rod" the level line across the water course by taking rod readings on hubs on both banks from instrument set-ups on both sides of the water course. Set permanent bench marks on both banks where they will not be disturbed by clearing or construction operations.

Unless the water is shallow and the current slow enough that stakes can be driven in the stream bottom, the taking of bottom elevations is done during the site mapping, when two men are available to chain and rod in the same operation. Methods of obtaining bottom elevations are given in Article 571.5.

571.4 SITE MAPPING. Plot the center line traverse on a large scale "hardshell". The scale will depend upon the contour interval to be used in mapping. If the contour interval is to be 2 feet, use a plotting scale of 1 inch = 20 feet. Take a tracing or hard copy, mount it on a board and take into the field for mapping topography. Locate the contours with hand level and rod by the method in Article 551.1. Plot the contour points and draw the contours connecting them. Plot all identifiable water lines, including extreme high water from marks on trees, average high water at the edge of vegetation, existing water, and low water lines at the end of the dry season. Topography should be mapped about 100 feet each side of the center line.

571.5 BOTTOM ELEVATIONS.

1. <u>In shallow water.</u> If the water course is fordable, elevations are taken with engineer's level or hand level and two rods, chaining distances between rods, with the rodmen-chainmen alternating in going ahead so as not to lose the chaining points. Points should be taken at sufficiently close intervals to give a good profile of the bottom.

2. <u>In deep water.</u> On a river where a boat or raft must be used, take soundings at intervals with a weight attached to a short tape which has each foot graduated. Measure distances from a long tape stretched above the water. If that is not feasible, use two transits set up on the ends of a base line and locate the sounding points by triangulation. The two transitmen turn simultaneous angles from "butterfly" back sights on the base line to a signal mounted on the boat, when the man taking the soundings calls "Mark". He reads the sounding. The notekeeper deducts the distance from the zero mark on the tape to the bottom of the weight and records the depth of water and the two angles. The topographer plots the sounding point by

protractor at the intersection of the two lines from the transit points. Changing water levels during the period of the operations are noted on a long stake marked in feet and tenths, driven into the bottom near the shore.

3. Bottom contours. If the anticipated sites of bridge abutments extend below the present water, the surrounding bottom should be mapped with 2 feet contour interval. If a mid-span pier will be required the entire bottom should be contoured. Bottom profile elevations are taken parallel to the center line, and the contours interpolated. The location of drift wood piles and of obstructions such as bars and rocks are mapped. It is of particular importance to map upstream obstructions which would deflect drift during flood stage.

4. Safety. The men working in or on swift or deep water should wear life jackets, and, if the current is strong, be attached with a rope snubbed to a tree or rock, and payed out by a man on the shore.

571.6 SOILS AND MATERIALS. At the possible sites of abutments and piers, the soils, underlying materials, and depth to bed rock should be ascertained by digging test pits or drilling. The "Reflecting Seismograph" is a useful tool for measuring depth to bed rock sub grade foundation soils for approach fills. All this information is noted on the map. Any exposed rock is accurately mapped. The location of suitable subgrade fill materials and concrete abutment aggregates, should be shown, or noted if outside the map area.

571.7 PLAN AND PROFILE. Plot the profile of the center line on the scale of 1 inch = 10 feet both horizontally and vertically. Plot the bed rock profile where depths to bed rock were taken. Show high and low water elevations. Draw the proposed grade line and bridge deck line. Trace the topographic map and the profile on "plan and profile" tracing paper. To compensate for any distortion in the field map, trace the center line first from the "hardshell" and then lay the tracing over the field map, adjusting the position of the center line by sections if necessary.

572 CULVERT SITE SURVEY

572.1 ADDITIONAL DATA REQUIRED. Where the peak flow of a stream can be carried by a large multi-plate corrugated metal culvert, or a concrete pipe or box culvert, and conditions are otherwise suitable for crossing the stream with a fill instead of a bridge, a culvert site survey is advisable. The culvert site survey is similar to the bridge site survey with the addition of collection of data necessary to compute the volume of water to be carried by the culvert:

1. A profile of the stream bed is run with engineer's level and rod for 500 feet each side of center line.

2. A cross section of the stream bed perpendicular to the axis of the culvert is taken, between extreme high water marks at road center line. This cross section is used to compute the wetted perimeter.

3. The velocity of the stream, at flood stage if obtainable. If a flow meter is not available, an approximation may be obtained by timing the travel of blocks of wood or fluorescent bobbers over a measured distance.

4. The stream bed materials and relative roughness of the bed.

580 SUPPLEMENTARY FIELD DATA

581 DATA FROM EXISTING ROADS

581.1 DATA TO OBTAIN. The best guide to road design is experience with existing roads in the same locality or roads on similar soils where other conditions are comparable. The existing roads referred to should preferably have been through at least one winter season. The following data will be of help to the road designer:

1. Soils. Identify the soils from the soil profile in cuts. Note the depth of overburden to rock. If subsidence of embankments has occurred, note them and endeavor to ascertain the cause. Note any slides and the cause.

2. Bank slopes. Measure the cut and fill bank slopes. If they hav not reached the angle of repose, note the degree of erosion, the extent of ditch filling, and other evidences of any inadequacy of the slopes.

3. Culverts. Measure the diameters and gradients of the culverts and note evidence of their adequacy. Such evidence may include inlet pool elevation marks with reference to the top of the culvert, and high water marks in the culvert, if capacity flow has never been reached. Note any scour in non-coated culverts. If any outlet erosion has occurred, note the conditions which caused it and how it could have been avoided. Note any distortion or subsidence of culverts under high fills. Note any evidence of plugging or erosion under or around the culvert.

4. Ditches. Note the depth and width of the ditches and evidence of their adequacy. Where ditches have overflowed onto the road surface, also note the ditch gradient and whether overflow was due to lack of ditch capacity or plugging of ditch.

5. Surfacing. Measure the thickness of surface course and base course and note how the surface has fared under traffic. A comparison of the present thicknesses with the original design thickness will give the road designer a basis for determining the specifications for the new road.

582 DATA FROM SURVEY ROUTE

582.1 GROUND COVER. The right-of-way will usually be cruised for appraisal of right-of-way timber. This cruise usually is the basis for estimating the cost of clearing and grubbing. Any other factor which will affect these costs should be noted on the right hand page of the field notes. These may include brush, reproduction and unmerchantable snags and windfalls. In second growth forest the size, frequency and relative soundness of old stumps which will have to be grubbed should be noted. If the right-of-way is not to be cruised, the type, size and estimated volume per acre is recorded

582.2 SOILS. The soil survey for a forest road project is covered in Chapter 660. If such a survey is not to be made, the following should be noted:

1. The sub grade soils along the road survey. (Chapter 620) Use the symbols given in Article 621.2.

2. If excavation material is not suitable for embankments, note the location of suitable borrow.

3. Note whether valley soils are suitable for fill foundations.

4. Record the depth of the organic soil layer to be stripped.

582.3 ROCK. Show the location and volume of rock suitable for surfacing, the kind of rock, and whether it can be excavated with a shovel or ripper, or requires blasting. Where rock outcrops occur along the right-of-way note their position with reference to the center line, and describe them. Give the estimated swell of the rock. Give the depth of overburden to bed rock, where it can be determined by probing with a bar, or measured with a "Reflecting Seismograph".

582.4 DRAINAGE PROBLEMS. Record all data which will help to determine the sizes of culverts. (Chapter 720) These will include size of stream (cross section area at high water), slope of stream above and below the culvert, creek bed materials, obstructions in the stream valley, elevation of high water mark. The drainage area will usually be obtained from a topographic map or aerial photo. The ground cover on the drainage area is required. If no map or photo is available, estimate the acreage of the drainage area. Note any special drainage problems which exist, such as springs, seepage areas, sidehill swamp, and ponded depressions above the road route.

582.5 OTHER PROBLEMS. Record any evidence of other conditions which may create problems in road construction or maintenance. Problem areas may include slides or other evidences of instability of the soil. On steep side hills the desirability of clearing right-of-way wider than usual should be noted. Wider clearing may be needed for slash disposal on the lower side or to reduce the weight above the cut bank.

How the right-of-way timber and the settings adjacent to the road will be logged, is an important consideration in logging road location and design. Areas suitable for landings for settings, or for cold decks for right-of-way timber, should be sketched on the right hand page of the location field book.

CONTENTS

600 SOIL ENGINEERING

610 SOILS AS MATERIALS OF CONSTRUCTION

611 INTRODUCTION

611.1 IMPORTANCE OF SOILS IN ROAD ENGINEERING. To obtain the construction of permanent forest roads, and to minimize maintenance, necessitates consideration of the engineering properties and characteristics of the forest soils. The soil is the construction material of the road subgrade. Coarse-grained soil (gravel) or rock, the parent material of the soil, is the construction material of the pavement structure of all-weather roads. It is as important to know the properties of these materials as it is to know the properties of materials used in designing a bridge. The properties of soils relating to erosion and infiltration of water affect the design of drainage structures. Thus the soil is an important consideration in every step of road engineering: reconnaissance, location, design and construction.

Yet soils engineering has been the most neglected phase of forest road engineering. Surfacing failures, subgrade failures, slides and washouts, with resulting high maintenance costs and slowed or interrupted traffic, testify to this neglect.

It is presumed that the forest road engineer using Division 600 has had introductory courses in geology and forest soils, which are included in the curricula of most forest schools and knows the parent materials and how soils are formed. Emphasis is placed on soil mechanics and methods of testing and identification which can be used in the field. References to standard soil mechanics laboratory tests are made in the expectation that they will find increasing use in the future.

611.2 NEED FOR SOILS INVESTIGATION. Investigation of the soils along the road route by some type of soil survey is needed for many purposes. Depending upon the factors governing (Article 661.1), the soil survey may range from a reconnaissance type of survey to an intensive soil profile survey. Following are some of the purposes for which a soil survey may be needed:

1. To avoid construction problem areas such as potential landslides, poorly-drained areas, and soils of low load-carrying capacity.

2. To locate suitable fill materials and surfacing rock.

3. For guidance in road prism design such as the relative cut and fill bank slope ratios, stability of embankments, etc.

4. To determine the bearing strength of the subgrade and the pavement structure (surfacing) design.

5. To assist in the design of adequate drainage facilities. For example, culvert spacing depends on soil as well as gradient.

6. To help plan erosion control measures.

7. For control of materials during construction.

8. For logging planning, silviculture and other forest management purposes.

612 ENGINEERING PROPERTIES AND CHARACTERISTICS OF SOIL

612.1 BASIC PROPERTIES. Soils have basic engineering properties that determine their characteristics as materials of construction. The most important factors affecting the properties are soil grain size and gradation of sizes, and moisture content. Moisture content is the amount of water in a soil expressed as a percentage of the dry weight. The basic properties of importance to the road engineer are noted briefly below.

1. Cohesion. The tendency of soil particles to stick together. Cohesion is high in clay and low in sand. Cohesion in a given soil varies with moisture content.

2. Internal friction. The resistance of soil particles to sliding against each other. It is also termed "intergranular friction." Such friction is high in sand and low in clay. Friction varies with grain size and shape.

3. Compressibility. The ability of a soil to be reduced in volume under compression, and to remain compressed after the load is removed. Compressibility is related to plasticity, the ability to be deformed without crumbling.

4. Elasticity. The ability of a soil to rebound and expand after it has been compressed. Elasticity is an undesirable property in subgrade soils.

5. Shearing strength. The measure of the ability of a soil to resist shearing stresses, such as under a wheel load. Cohesion and internal friction are the properties contributing to shearing strength. It is also affected by compressibility and elasticity. The shearing strength determines the load-bearing capacity. In gravel-sand-clay mixtures the gravel and sand contributes high internal friction, and the clay high cohesion, to develop shearing strength.

6. Permeability. The ability of a soil to transmit gravitational water. It is influenced mainly by grain size and density of the soil mass. Gravels and sands are permeable. Some fine-grained soils are impervious. Permeability determines drainage characteristics.

7. Capillarity. The ability of a soil to lift water by surface tension. Silts have high, rapid capillarity. Capillarity in clays is high, but slow. Gravels and sands have low capillarity. Frost action is related to capillarity.

8. Shrinkage. As moisture content is reduced, fine-grained soils shrink in volume until the "shrinkage limit" is reached. Beyond this point there is no decrease in volume with further reduction in moisture content.

For study of soil properties reference (1/) is recommended.

612.2 CHARACTERISTICS DETERMINED BY PROPERTIES. The basic engineering properties determine the characteristics of a soil as a material of construction. The characteristics of the various soil groups by the Unified Soil Classification System are given in tabular form in Article 612.3. The soil groups in Column 1 are explained in Section 621. The following characteristics conform to the headings of the columns in the table:

1. Value as subgrade. Column 2. The structural strength of a soil is determined by a combination of its properties of cohesion, internal friction, compressibility and elasticity. Column 2 gives a general indication of the suitability of each soil group as a subgrade provided it is not subject to frost action. The value is reduced if subject to frost action, Column 6. One widely-used measure of the bearing strength or load bearing capacity of a subgrade soil is the CBR (California Bearing Ratio, Article 631.3). Column 3 gives the range at CBR values usually found in each soil group. Columns 2 and 3 are used in both subgrade and pavement structure (surfacing) design.

2. Drainage characteristics. Column 4. Drainage characteristics are determined by the properties of permeability and capillarity and by grain size and porosity. The soil groups rated "Excellent" under Column 4 are free-draining. However, they also permit rapid infiltration of water into the base or subgrade if the water is not diverted. Because of the influence of moisture content on all soil properties, Column 4 is used in designing subgrade and pavement as well as drainage structures.

3. Erosion Index (E.I.). Column 5 is the measure developed by the U. S. Forest Service and published in reference (9/). Erosion indices range from 10, the most erosive, (SM and ML groups) by tens, to 100 for the least erosive, (rock, coarse volcanic cinders, cobble and coarse gravel, GW and GP groups). The erosion index of mixtures of soil groups is computed by the following formula:

$$\text{Total EI} = \Sigma(\text{percent each soil group X E.I. for each group})$$

Example: A road goes through 20% GP, 30% GC and 50% CH soils. The total EI is computed:

GP	20%	x	100	=	20
GC	30%	x	70	=	21
CH	50%	x	60	=	30
	Total EI				71

Erosion index is one of the factors to be considered in the spacing of lateral drainage culverts (Article 650.2). It is also applicable to determination of erosion control measures. Special cases of highly erosive materials found in Western Oregon are:

Highly decomposed granites; decomposed granodiorite, EI 10
Moderately decomposed granites; decomposed sandstone, EI 20
Greasy, clayey decomposed rock; micaceous soils, EI 30

4. Frost action. Column 6. This column gives the relative susceptibility of the group to frost heave. When water is present in the subgrade during periods of frost penetration, ice lenses form. The consequent expansion lifts the surfacing which is broken up by moving wheel loads. Frost action is often associated with capillarity. Frost action is a consideration in use and maintenance of a road as well as design. High frost action calls for seasonal closure of the road to heavy trucks. Column 6 is used in subgrade and pavement structure design.

5. Compressibility and expansion. Column 7. The compressibility and expansion of a soil group is determined by the properties of compressibility and elasticity of the constituent soils and their proportions in the group. This column is used to determine the suitability of a soil, first as a foundation under a fill for long-term consolidation, and, second, as a subgrade where short-term compression and rebound under traffic is the consideration.

6. Compaction characteristics. Column 8. Compaction is related to (5) above. Column 9 gives the ranges in dry weight in lb. per cu. ft. for compacted soil at optimum moisture content for modified AASHO compactive effort.

Following is the compaction equipment recommended by the Corps of Engineers to obtain the required density, when moisture content and layer thickness is controlled. Minimum equipment loadings specified are: Crawler tractor 30,000 lbs., rubber-tired wheel load 15,000 lbs., sheepsfoot roller 250 p.s.i.

Equipment	Soil Group
Crawler tractor	GW, GP, SW, SP
Steel-wheeled roller	GW, GP
Rubber-tired roller	All groups excepting MH, CH, OH
Sheepsfoot roller	All groups excepting GW, GP, SW, SP

Note: Close control of moisture is required for GMd, SMd, and ML groups.

612.3 CHARACTERISTICS OF SOIL GROUPS FOR ROAD CONSTRUCTION
Unified Soil Classification System

U.S.C.S. Symbol	Value as Sub-Grade*	Field CBR Value	Drainage Character- istics	Erosion Index	Frost Action	Compress- ibility and Expan- sion	Compaction Character- istics	Dry ** Weight lbs./cu.ft.
1	2	3	4	5	6	7	8	9
GW	Excellent	60-80	Excellent	100	None to very slight	Almost none	Good	125-140
GP	Good to excellent	25-60	Excellent	100	None to very slight	Almost none	Good	110-130
GM d	Good to excellent	40-80	Fair to poor	60	Slight to medium	Very slight	Good	130-145
GM u	Good	20-40	Poor to impervious	50	Slight to medium	Slight	Good	120-140
GC	Good	20-40	Poor to impervious	70	Slight to medium	Slight	Fair	120-140
SW	Good	20-40	Excellent	80-90	None to very slight	Almost none	Good	110-130
SP	Fair	10-25	Excellent	80-90	None to very slight	Almost none	Fair to good	100-120
SM d	Good	20-40	Fair to poor	20	Slight to high	Very slight	Good	120-135
SM u	Fair to good	10-20	Poor to impervious	10	Slight to high	Slight to medium	Good	105-130
SC	Fair to good	10-20	Poor to impervious	50	Slight to high	Slight to medium	Fair	105-130
ML	Fair to poor	5-15	Fair to poor	10-20	Medium to very high	Slight to medium	Good to poor	100-125
CL	Fair to poor	5-15	Practically impervious	40	Medium to high	Medium	Good to fair	100-125
OL	Poor	4-8	Poor	30-40	Medium to high	Medium to high	Fair to poor	90-105
MH	Poor	4-8	Fair to poor	30-40	Medium to very high	High	Poor to very poor	80-100
CH	Poor to very poor	3-5	Practically impervious	50-60	Medium	High	Fair to poor	90-110
OH	Poor to very poor	3-5	Practically impervious	50	Medium	High	Poor to very poor	80-105
PT	Unsuitable		Fair to poor		Slight	Very high	Fair to poor	

* Value as subgrade, foundation or base course (except under bituminous) when not subject to frost action.
** Unit dry weight for compacted soil at optimum moisture content for modified AASHO compactive effort.

620 CLASSIFICATION AND IDENTIFICATION OF SOILS

621 UNIFIED SOIL CLASSIFICATION SYSTEM

621.1 RECOMMENDATION. Several systems of soil classification have been developed. The silviculturist uses a classification which relates to the soil to site quality for tree growth. The Bureau of Public Roads and State Highway Departments use the AASHO classification system which is based on grouping soils by load-carrying capacity. Seven groups are recognized, ranging from A-1 to A-8. They are explained in reference 12/. The Unified Soil Classification System developed by the Corps of Engineers (2/) is recommended as the most practical for use by forest road engineers. With experience, most of the broader soil groups may be identified in the field by simple test. Precise differentiation between some of the fine-grained soil groups requires laboratory tests. Having identified the soil groups found, their relative values as road construction materials is readily ascertained from the table in Article 612.3.

The following development is arranged to facilitate understanding and use of the Unified Soil Classification System.

621.2 SOIL SYMBOLS AND DESCRIPTIONS.

SYMBOL	NAME	
		(a) Based on Texture (1) Coarse grained soils - Individual grains visible to naked eye
G	Gravel	Deposits of rock fragments, usually rounded by water action and abrasion. More than half larger than 3/16 inch size range up to 3 inches. For visual classification, ¼ inch may be used for larger than No. 4 sieve. (Fragments larger than 3 inches are termed "Cobbles," larger than 12 inches, "Boulders.")
S	Sand	Loose unconsolidated fragments of rock. More than half larger than No. 200 sieve size (0.003 inch - the smallest size visible to the eye). Range up to No. 4 sieve size (3/16 inch). Grains feel gritty. Sand lacks cohesion; wet sand crumbles when squeezed.
		(2) Fine-grained soils - Smaller than No. 200 sieve size or 0.003 inch. Individual grains not visible or barely visible to the naked eye.
C	Clay	Aluminum silicate (Kaolinite) mixed with silica and compounds of iron, calcium and magnesium. Extremely fine grained; individual particles not visible to the naked eye. Smooth, slippery feel, dense and compact, forming very hard clods when dry. Plastic; can be kneaded like dough. Medium to high dry strength.

M	Silt	Fine granular material, inorganic silt, rock floor. Particles barely visible to the eye. Floury or velvety feel. Lacks plasticity and has little dry strength. Symbol "M" is also used for very fine sand.
O	Organic	Presence of organic matter formed by decomposition of vegetable or animal matter. Evidenced by odor or color. Distinctive odor from fresh samples, or from heated wet samples. Dark or drab gray or brown, or black colors. (Inorganic materials have bright colors)
		(b) Based on Plasticity and Compressibility
L		Low to medium plasticity and compressibility. Liquid limit less than 50 (Liquid limit is the moisture content at which a soil passes from a plastic to a liquid state. The liquid limit test is an index of cohesion since cohesion has been largely overcome at the liquid limit).
H		High plasticity and compressibility. Liquid limit greater than 50.
		(c) Based on Gradation
W		Well graded. An even division of all material by both size and quantity. Wide range in grain sizes with all intermediate sizes.
P		Poorly graded. An uneven or erratic division of material. Mainly one size, or a range of sizes with intermediate sizes missing.

621.3 OUTLINE OF UNIFIED SOIL CLASSIFICATION SYSTEM

- Coarse-grained soils
  - Gravels
    - Clean, little or no fines
      - Well graded — GW
      - Poorly graded — GP
    - Appreciable amounts of fines
      - Silty gravels — GM
      - clayey gravels — GC
  - Sands
    - Clean, little or no fines
      - well graded — SW
      - poorly graded — SP
    - Appreciable amount of fines
      - silty sands — SM
      - clayey — SC

- Fine-grained soils
  - Silts and Clays
    - Slight to low plasticity, liquid limit < 50
      - Inorganic
        - Silts, clayey fine sands or silts — ML
        - clays, sandy or silty or lean clay — CL
      - Organic
        - silts or silty clays — OL
    - Medium to high plasticity, liquid limit > 50
      - Inorganic
        - silts — MH
        - clays, fat clays — CH
      - Organic
        - clays silts — OH

621.4 SOIL GROUPS

(a) Coarse grained soils

GRAVELLY SOILS		SANDY SOILS	
SYMBOL	NAMES	SYMBOL	NAMES
GW	Well graded gravels Gravel-sand mixtures (Little or no fines)	SW	Well graded sands, Gravelly sands (Little or no fines)
GP	Poorly graded gravels Gravel-sand mixtures (Little or no fines)	SP	Poorly graded sands, Gravelly sands (Little or no fines)
GM*	Silty gravels. Gravel-and-silt mixtures (Non-plastic fines or fines with low plasticity)	SM*	Silty sands, sand-silt mixtures (Non-plastic fines or fines with low plasticity)
GC	Clayey gravels. Gravel-and-clay mixtures (Plastic fines)	SC	Clayey sands, sand-clay mixtures (Plastic fines)

* GM and SM groups are further subdivided into "d" and "u". Suffix "d" is used when liquid limit is 28 or less and the plasticity index is 6 or less. Suffix "u" is used when liquid limit is greater than 28. This subdivision requires laboratory test (Article 623.1).

(b) Fine grained soils

SYMBOL	NAMES	FIELD IDENTIFICATIONS*			
		Plasticity**	DRY STRENGTH	DILATANCY	TOUGHNESS
ML	Inorganic silts and very fine sands, silty or clayey fine sands. Clayey silts, Rock flour	Slight	None to slight	Quick to slow	None
CL	Inorganic clays, gravelly or sandy or silty or lean clays	Low to medium	Medium to high	None to very slow	Medium
OL	Organic silts, organic silty clays	Low	Slight to medium	Slow	Slight
MH	Inorganic silty, elastic		Slight to medium	Slow to none	Slight to medium

SYMBOL	NAMES	FIELD IDENTIFICATIONS*			
		Plasticity**	DRY STRENGTH	DILATANCY	TOUGHNESS
CH	Inorganic clays, fat clays	High	High to very high	None	High
OH	Organic clays, organic silts	Medium to high	Medium to high	None to very slow	Slight to medium
PT	Peat, other highly organic soils	Color, odor, spongy feel, fibrous texture			

For field tests see Article 622.2.
**Plasticity is the property which allows soil to be deformed beyond the point of recovery without cracking or appreciable volume change.

622 FIELD TESTS FOR SOIL IDENTIFICATION

622.1 IDENTIFYING COARSE GRAINED SOILS. Following are field tests for gravels or sands:

1. Gradation. Spread a dry sample thinly on a flat surface. Separate the coarse grains into groups of approximately uniform size, from largest to the smallest which can be handled. Note whether the soil is (a) well graded (Symbol W) with an even division by both size and quantity of a wide range of grain sizes with intermediate sizes present; or (b) poorly graded (Symbol P) with an uneven or erratic division mainly one size, or a range of sizes with intermediate size missing.

2. Testing for fines; settling test. Mix soil and water in a test tube or a glass jar, such as an olive jar. Shake thoroughly and let settle. The coarse grains will fall to the bottom first. Successively finer particles will settle out of suspension with increasing time. Sands will settle in 20 to 30 seconds. The fines will settle last. The depth of the layer of fines as compared with the depth of the coarse grained material will indicate the percentage of fines.

3. Decantation test. Mix a measured amount of soil with water in a jar or can. Pour off the turbid water containing the fines. Repeat the mixing and decanting until all the fines are removed and only the sand and gravel is left. The amount left compared with the original amount will give an approximate measure of the fines.

4. Percentage of fines. Less than 5 percent fines classifies the soil as having "little or no fines," groups GW, GP, SW, or SP.

More than 12 percent fines classifies the soil as having "appreciable amounts of fines", groups GM, GC, SM, or SC.

Soils having between 5 percent and 12 percent fines are classed as borderline soils and designated by two group symbols as "GW - GM," or "GW - GC."

622.2 IDENTIFYING FINE GRAINED SOILS.

1. Distinguishing fines. Rub the soil between thumb and fingers. Silt or clay feel smooth and stain the fingers. Fine sand feels gritty and does not stain. Bite a sample between the teeth. Sand feels gritty and clay and silt do not. Clay tends to stick to the teeth; silt does not. Clay feels sticky when wet.

For the following tests, remove all particles larger than No. 40 sieve size, or approximately 1/64 inch.

2. Dry strength. (Crushing characteristics) Mold a pat of soil of one half cubic inch volume to consistency of putty, adding water if necessary. Dry in sun. Test strength by breaking and crumbling in fingers. The dry strength increases with increasing plasticity. "CH" soils have high dry strength. Silty fine sands and silts have similar, slight dry strength, but can be distinguished by feel: sand feels gritty, silt feels smooth like flour.

3. Dilatancy. (Reaction to shaking) Make a pat of moist soil, adding water to make soft but not sticky. Place pat in open palm of one hand. Shake horizontally, striking against other hand several times. Reaction is appearance of water on surface, livery consistency and glossy appearance. When pat is squeezed, water and gloss disappear, the pat stiffens and finally cracks or crumbles. Rapidity of appearance of water on shaking, and of disappearance on squeezing, indicates the character of the fines. Very fine clean sand gives quickest reaction; plastic clay gives no reaction.

4. Toughness. (Consistency near plastic limit) Mold a pat to consistency of putty, adding water if necessary. If sticky, spread out in thin layer to dry. Roll between palms or on smooth surface to 1/8 inch diameter thread. Fold the thread and re-roll repeatedly. The moisture content is gradually reduced during the operation, the soil stiffens and loses its plasticity. It finally crumbles when the plastic limit is reached. After the thread crumbles, lump together and knead until the lump crumbles.

The more colloidal clay in the soil the tougher the thread near the plastic limit and the stiffer the lump. Weak thread and quick crumbling below the plastic limit indicated inorganic clay of low plasticity or organic clay below the "A" line on the plasticity chart. Highly organic clays feel weak and spongy at plastic limit.

Bearing strength decreases very rapidly as moisture content is increased above the plastic limit. The converse is true for decrease in moisture content.

5. Pocket Penetrometer. The "Pocket Penetrometer" (3/) is an

inexpensive instrument which will aid in classifying cohesive types of soils. The piston of the penetrometer is pushed into the soil up to a calibration groove. A pointer attached to a calibrated spring gives a scale reading in tons per sq. ft. or Kg. per sq. cm. The instrument is 3/4 inch in diameter by 7-3/8 inches long and weighs only 4 oz. It was developed for use in the field to check visual classification of cohesive types of soils. It is also used for checking degree of soil compaction, failure or slide areas and soil strata.

623 LABORATORY TESTS FOR SOIL CLASSIFICATION

623.1 ASTM STANDARD TESTS. ASTM is the abbreviation of American Society for Testing Materials. The letter and number following ASTM is the Standard Test designation. The final number, following the dash, is the year of adoption. A final "T" stands for "Tentative." (4/) The following are brief descriptions of tests used for distinguishing the groups of fine-grained soils in the Unified Soil Classification System. Bureau of Public Roads FP-57 uses the American Association of State Highway Officials (AASHO) test designation.

1. Liquid limit. ASTM D 423-54 T AASHO T89 The liquid limit (L.L.) is the moisture content at which a soil passes from a plastic to a liquid state. The test is made by determining the number of blows on a standard laboratory cup required to bring the bottom of a triangular groove separating two portions of the soil sample into contact for 0.5 inch. Data for a number of moisture contents are plotted as a "flow curve." The moisture content at the 25 blow line is the L.L.

Sandy soils have low liquid limits of about 20. Clays have liquid limits of 40 to 60. Silts and clays may have liquid limits as high as 80 to 100.

2. Plastic limit. ASTM D 424-54 T AASHO T91 The plastic limit (P.L.) is the moisture content at which a soil changes from a semi-solid to a plastic state. This is the lowest m.c. at which a sample can be rolled into 1/8 inch threads without breaking. Starting with moist soil, the m.c. is reduced by alternate kneading and rolling until the thread crumbles. P.L. is governed by clay content. Bearing strength decreases very rapidly with increase in m.c. above the P.L.

3. Plasticity index. The plasticity index (P.I.) is the numerical difference between L.L. and P.L. The P.I. gives the range of moisture content in which the soil is in a plastic state. A small P.I. indicates a small change in moisture content will change the soil from semi-solid to liquid. A large P.I. shows that the soil can absorb considerable water before changing from semi-solid to liquid. The "Plasticity Chart" used in laboratory classification of the groups of fine-grained soils in the Unified Soil Classification System is given in Figure 623-2.

4. Moisture equivalent tests. ASTM D 426-39

   a. Field Moisture Equivalent (F.M.E.) is the minimum moisture content at which a drop of water placed on smooth surface of soil will not be absorbed in 30 seconds. The water spreads over the surface and gives it a shiny appearance. It shows when cohesive soils approach saturation, and when all the pores in sands are filled with water.

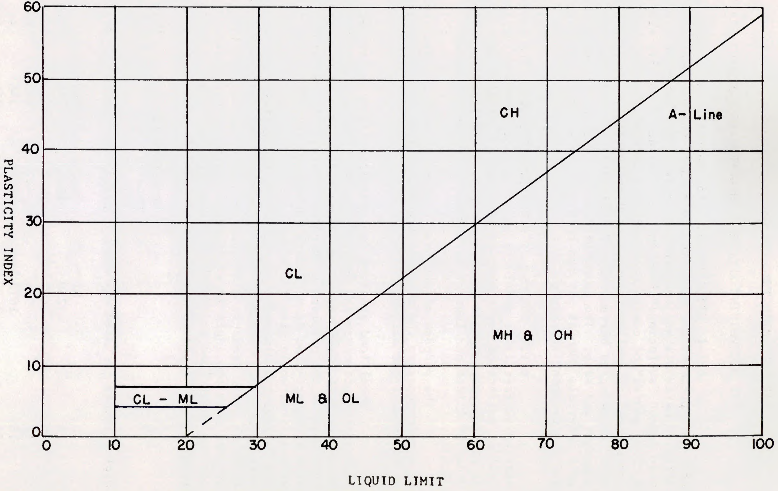
b. Centrifuge Moisture Equivalent (C.M.E.) ASTM D 425-39, is the moisture content after a saturated sample is centrifuged for 1 hour. Low values, as less than 12, indicate impermeability and high capillarity. When F.M.E. is greater than C.M.E., soil is elastic and will contract under wheel load and expand when this load is removed.

5. Grain size analysis. ASTM D 422-54 T. The soil sample is dried, aggregations broken up with mortar and pestle, and sieved through progressively smaller sieves of sizes on which classification is based, and as required for further tests, such as No. 4, No. 10, No. 40 and No. 200 sieves. The various fractions are weighed. Distribution of particle sizes smaller than No. 200 sieve is by sedimentation of a soil-water slurry, taking hydrometer readings at intervals of time.

U.S. Standard Sieve Openings

No.	Inch	MM	Microns
4	0.187	4.76	4760
10	0.0787	2.00	20C0
12	0.0661	1.68	1680
40	0.0165	0.42	420
200	0.00029	0.074	74

FIGURE 623-2 PLASTICITY CHART



630 PAVEMENT STRUCTURE DESIGN

631 DETERMINING REQUIRED THICKNESS OF PAVEMENT STRUCTURE

631.1 DEFINITIONS. The "subgrade" of a road is the natural soil prepared and compacted to support the pavement structure of selected materials and the traffic loads. The "pavement structure," also termed "surfacing," "topping" or "ballast," usually consists of a "base course" of coarse material laid on the subgrade, and a "wearing course" of smaller material laid on the base. Sometimes a "subbase" of selected borrow, or a fliter layer of sand, is used between subgrade and base. The term "ballast" is customarily used when the same material, such as pit run rock with soil binder, is used throughout the pavement structure.

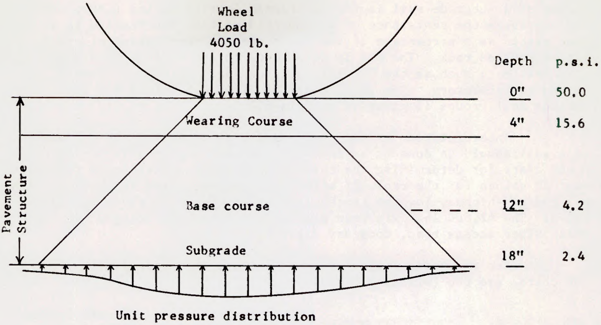
631.2 PURPOSE OF PAVEMENT STRUCTURE. The purpose of the wearing surface is to provide a smooth durable running surface of low rolling resistance for rubber-tired traffic. It also serves as a "roof" to protect the subgrade from rain water. Good practice calls for a crown of ¼ inch per foot of half-width to drain the water.

The purpose of the base course is to distribute surface loads to a unit pressure the subgrade can support; to provide drainage, and to minimize frost action.

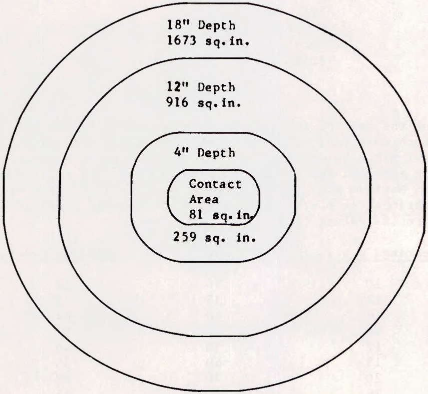
Wheel load pressure is transmitted from the surface through the pavement structure to the subgrade in the form of a frustrum of a cone. Hence the unit pressure on the subgrade decreases with increase in the thickness of the pavement structure. For example, a 10:00 x 20 tire, with a contact area of 81 square inches, on 16,200 lb. log truck axle with 4 tires would give a surface load pressure of 4050 lbs. or 50 p.s.i. The following table shows pressure area and average unit pressure at various depths. (Actually unit pressure is not uniform but varies as shown by "Unit Pressure Distribution" curve in Fig. 631-1) 11/. It is assumed that the angle is 45 degrees. Average unit pressure may be found for any wheel load and depth "d" from formula: p.s.i. = wheel load/$\pi (r+d)^2$ where "r" is radius of circle equal in area to tire contact area.

		Unit pressure under 1 tire		Unit pressure under dual tires	
Depth, inches	Area sq. in.	p.s.i.	p.s.f.	p.s.i.	p.s.f.
0	81	50	7200		
4	259	15.6	2246	30.0	4492
6	401	10.1	1454	20.2	2908
12	916	4.2	605	8.4	1210
18	1673	2.4	346	4.8	692
24	2657	1.5	230	3.0	460

631.3 SUBGRADE BEARING STRENGTH. The design of the pavement structure starts with the determination of the bearing strength of the subgrade. Recommended as a useful measure of bearing strength of



Wheel
Load
4050 lb.
Depth
p.s.i.
0"
50.0
Wearing Course
4"
15.6
Pavement
Structure
Base course
12"
4.2
Subgrade
18"
2.4
Unit pressure distribution



18" Depth
1673 sq.in.
12" Depth
916 sq.in.
4" Depth
Contact
Area
81 sq.in.
259 sq. in.

FIGURE 631-1

forest road subgrade soil is the California Bearing Ration (CBR). The CBR expresses the resistance of a compacted soil to penetration by a test piston as a percentage of the resistance to penetration of compacted crushed rock. The CBR is determined in the field with a portable test set, such as the "CN-727 Field CBR Set" (3/) or in a soil mechanics laboratory. The usual range of Field CBR Values for the various soil groups is given in Article 612.3.

Interpretation of CBR test results to determine the CBR value of a soil should be done by an engineer specializing in soil mechanics. A CBR chart for determining the thickness of pavement structure for various CBR values for the range of axle loads commonly used for both on-highway and off-highway logging trucks in western Oregon is given in Figure 631-4. The 42,500 lb. axle load was used in designing bridges for the Smith River access road, Coos Bay district.

For thickness greater than 19 inches, the upper limit of the CBR chart, use the following table:

	Pavement Structure Thickness Inches		
Axle Load lbs.	CBR: 3	4	5
16,000	19.1		
18,000	20.0		
20,000	20.8	17.7	
24,000	22.4	19.1	
30,000		21.0	18.6
42,500		24.4	21.4

Tests of the bearing strength of subgrade soils may be made in the field. One such test (ASTM D 1196-57) penetrates the soil with a 30 inch diameter steel plate by a hydraulic jack, applied under a truck or trailer, measuring the load and deflection with gauges. The test is made at the anticipated maximum m.c. of the soil in service. Following are the equivalent bearings, in p.s.i. under a 30 inch diameter plate at 0.1 inch deflection, to CBR values (1/).

CBR	Bearings p.s.i.	CBR	Bearings p.s.i.
4	10	30	38
5	12	35	41
6	14	40	44
7	16	45	47
8	17	50	50
9	19	60	55
10	20	70	60
15	26	80	65
20	30	90	70
25	34		

In the absence of CBR or other standard test equipment, the use of the "Pocket Penetrometer," (Article 622.2-5) which measures the unconfined compressive strength of the soil, will give an indication of subgrade bearing strength.

631.5 OTHER FACTORS DETERMINING THICKNESS. Factors to consider in deciding upon the thickness of the pavement structure, other than CBR value, are: subgrade compaction, which will depend upon the construction methods used and the control of m.c. during compaction; subgrade drainage effectiveness; frost penetration and frost heave; and subgrade soil swell pressure.

The bearing strength of a soil mass depends on its density. The density varies with the soil group and with compactive effort and m.c. If the latter two are not to be controlled during construction to achieve the density on which the CBR is based, the thickness of the pavement structure should be increased. If the subgrade cannot be kept dry, due to inadequate drainage or to soil subject to capillarity, thicker pavement structure is needed. Swell pressure, like frost action, is associated with water in the soil. High-swelling soils are found among clays and clay-silts. Such clays are usually of the Montmorillonite type(5/). To restrain swell pressure requires increasing the weight of the pavement structure.

632 DESIGN OF PAVEMENT STRUCTURE COURSES

632.1 WEARING COURSE. Having determined the thickness of the pavement structure required on the various soil groups found in the subgrade, the next step is to determine the relative thickness of the base course and wearing course, and, in some cases, the subbase course.

The thickness of the wearing course will be governed by the resistance of available rock to abrasion and weathering; the type of rock, whether crushed stone, gravel or pit-run; the volume of traffic and the cost of surfacing material. Under heavy traffic, truck logging roads may lose one-half inch to an inch of surface a year in dusting and erosion.

As a general guide the following wearing course specifications for permanent Class II and III roads are recommended:

Material: Crushed rock or gravel
Hardness: Percentage of wear less than 50 (Article 633.2)
Weathering: Percentage of loss not more than 15 (Article 633.2)
Fragment size: Maximum 1 inch
Grading: From Table 300-1 FP (6/) Percent passing sieve opening:

Grading B

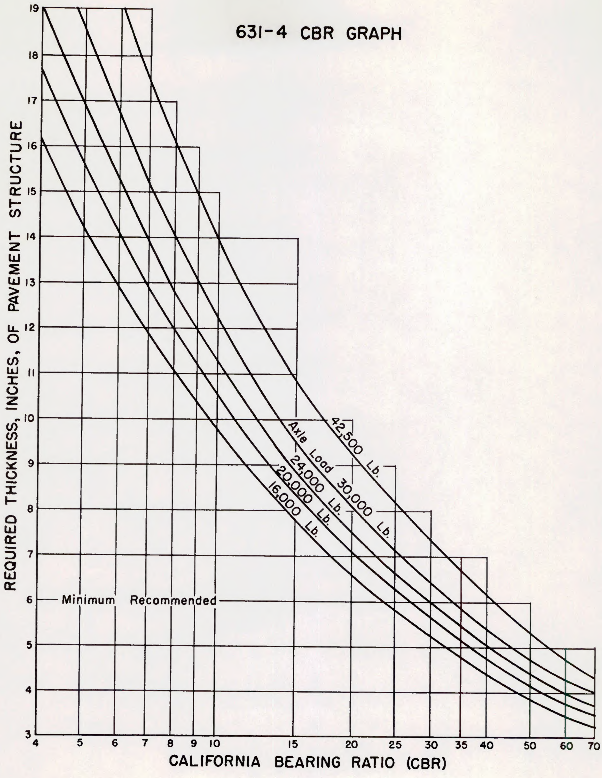
1 inch	100
No. 4	40-75
No. 10	25-60
No. 200	less than 12

Grading E

1 inch	100	No. 10	40-70
3/4 inch	85-100	No. 40	25-45
3/8 inch	65-100	No. 200	10-25
No. 4	55-85		

Plasticity: Portion passing No. 40 sieve L.L. not more than 35, P.I. not less than 4, or more than 9.
Thickness: Light traffic 3 in., medium traffic 4 in., heavy traffic 5 to 6 in.

Where pit run rock is used, the fragments in the top layer should not be larger than 2 in. as that is the largest size subject to satisfactory proces-


631-4 CBR GRAPH
REQUIRED THICKNESS, INCHES, OF PAVEMENT STRUCTURE
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
Minimum Recommended
Axle Load
42,500 Lb.
30,000 Lb.
24,000 Lb.
20,000 Lb.
16,000 Lb.
4
5
6
7
8
9
10
15
20
25
30
35
40
50
60
70
CALIFORNIA BEARING RATIO (CBR)

sing by grader.

632.2 BASE COURSE. The thickness of the base course equals the required pavement structure thickness minus the wearing course thickness. The base course material must have sufficient bearing strength to carry the unit pressure at the bottom of the wearing course. The fragments in the base should not be larger than 2/3 the base thickness, and preferably not larger than 3 inches. Base materials commonly used on logging roads are coarse gravel with a filler of sand, or pit run rock from road excavations or borrow pits. The following, condensed from FP 57 (6/), are desirable specifications for base material:

"102-2.2 Select Borrow for Topping" used for pit run. Gradation: Passing 3 inch sieve. Not more than 15 percent fines (passing No. 200 sieve) P.I. of fines not more than 6.

"200-2.1 Gravel." Hard durable fragments with filler of sand.

"200-2.3 General requirements." Graded from coarse to fine.

Free from organic matter and clay balls. Fines: L.L. not more than 25, P.I. not more than 6. Minimum grading: Passing 3 inch 100 percent; passing No. 4, 15 to 45 percent; passing No. 200, 0 to 10 percent.

632.3 SUB-BASE COURSE. The use of a sub-base course is indicated where segments of subgrade are unavoidably constructed in weak soil. A sub-base may be used to bring such segments up to strength for uniform base course thickness. Where rock or gravel is scarce, it may be economical to reduce the base course thickness by using a topping of selected borrow on the sub-grade.

A sub-base of soil of low capillarity and slight frost action may be needed on subgrade soils of high capillarity and frost action. A sand "blanket" or filter layer of sand is commonly used. The sand blanket will also prevent silt or clay from "pumping" up into the base (11/). This is especially desirable on "slippery" soils which would tend to lubricate the pavement structure fragments and facilitate their shifting under traffic load. The sand blanket is usually 4 to 6 inches thick and extends the width of the subgrade. It acts as a lateral drain for capillary water and for water infiltrating the surface. Sieve specifications for filter sand are: Passing 3/8 sieve and retained on No. 40 sieve (11/).

632.4 COMPACTION OF PAVEMENT STRUCTURE. Compaction of the surfacing material by roller in layers not thicker than 3 inches is essential to develop the bearing strength of the pavement structure and to make it smooth and water-tight. Recommended specifications for placing, spreading and compaction are Articles 200-3.3 to 200-3.6, FP 57 (6/). The importance of adding water to dry material for compaction should be emphasized. Before laying the base, the subgrade should be finished as specified in Article 107-3.1 FP 57. Compaction with the Hyster "Grid" Roller is covered in reference (12/).

The practice of leaving the compaction of the surface to the traffic results in compaction only of the wheel tracks and loss of uncompacted material pushed out on the shoulder or into the ditch. Water percolates through the surface and saturates the subgrade.

632.5 SURFACING AGGREGATE TABLES. The following tables of quantities of surfacing aggregate for various thicknesses, and of distance in lineal feet a given dump truck load will spread, will facilitate estimating and control of dumping and spreading. They are based on a pavement structure side slope ratio of 3:1 and on material which compacts to two-thirds the thickness of the loose aggregate.

CUBIC YARDS PER STATION, LOOSE MEASURE

Compacted Thickness Inches	Loose Thickness Inches	Road Class: III Surface Width: 12 feet	II 20 feet
2	3	11.8	19.2
3	4.5	18.2	29.3
4	6	25.0	39.8
5	7.5	32.1	50.6
6	9	39.6	61.8
7	10.5	47.4	72.8
8	12	55.6	85.2
10	15	72.9	109.9
12	18	91.7	136.1
14	21	112.5	164.3
16	24	133.3	192.5
18	27	157.0	223.7
20	30	180.6	254.7
24	36	233.3	322.2

DISTANCE IN LINEAL FEET A DUMP TRUCK LOAD WILL SPREAD

Loose Thickness Inches	Class III, 12 ft. surface width, cubic yards per load					Class II, 10 ft. or ½ of 20 ft. surface width, cubic yards per load					Class II 20 ft. surface width				
	1	3	5	7	9	1	3	5	7	9	1	3	5	7	9
3	8.47	25.4	42.4	59.3	76.3	10.42	31.2	52.0	73.0	93.8	5.21	15.6	26.0	36.9	46.9
4.5	5.49	16.5	27.5	38.5	49.4	6.82	20.4	34.2	47.8	61.4	3.41	10.2	17.1	23.9	30.7
6	4.00	12.0	20.0	28.0	36.0	5.02	15.0	25.2	35.2	43.2	2.51	7.5	12.6	17.6	22.6
7.5	3.11	9.3	15.6	21.8	28.0	3.95	11.8	19.8	27.6	35.6	1.98	5.9	9.9	13.8	17.8
9	2.52	7.6	12.6	17.7	22.7	3.25	9.8	16.2	22.8	29.2	1.63	4.9	8.1	11.4	14.6
10.5	2.11	6.3	10.5	14.8	19.0	2.75	8.2	13.8	19.2	24.8	1.37	4.1	6.9	9.6	12.4
12	1.80	5.4	9.0	12.6	16.2	2.34	7.0	11.8	16.4	21.0	1.17	3.5	5.9	8.2	10.5

633 TESTS OF SURFACING ROCK

633.1 FIELD TESTS. A rough field test of the suitability of gravel or fragmented rock for surfacing material is to crush individual particles on a large flat rock with a hammer, or a boulder. Weathered rock, which would be unsuitable for a wearing course, may be recognized by discoloration and ease of crushing.

Fragments of shale in surfacing will disintegrate under alternate wetting and drying. To test for shale, dry a measured sample in the sun, or in an oven. Soak in water for 24 hours. The shale will disintegrate. Pour off the water and dry. Re-measurement will indicate the amount of shale removed.

Rock subject to weathering may be recognized by its relatively light weight, ease of crushing, rounded fracture edges, greasy deposits in minute fracture planes, mottled colors, and iron stain. Rock suitable for wearing surface is relatively heavy in weight, hard, has sharp fracture edges, and is not mottled or stained.

Igneous rock is generally suitable for wearing surface. Sedimentary rock should be tested for resistance to abrasion and weathering before acceptance.

633.2 LABORATORY TESTS. If there is doubt regarding the suitability of the surfacing rock proposed to be used, it should be subjected to laboratory tests. The Los Angeles Abrasion Test (AASHO T 96 or ASTM C 131-55) is the standard test for wear. A 5000 gram graded sample of aggregate and an abrasive charge of steel balls is placed in a hollow steel cylinder, containing a projecting steel shelf. It is rotated for 500 revolutions at 30 to 33 RPM. The material passing a No. 12 sieve is screened out and the remainder weighed. The loss in weight divided by the original weight is the percentage of wear.

Resistance to disintegration, which is related to weathering, is tested by ASTM C 88-56T--soundness of aggregate by sodium sulfate or magnesium sulfate. The percentage of soft particles is found by ASTM C 235-57T--scratch hardness of coarse aggregate particles.

The fines passing a No. 40 sieve are tested for liquid limit and plastic limit and plasticity index. These tests are described in Article 623.1.

Acceptable specifications of aggregates are given in Section 632.

640 SUBGRADE COMPACTION

641 REQUIREMENTS FOR COMPACTION

641.1 FILL CONSTRUCTION METHODS. It is essential that the subgrade be compacted to the design density used in determining the thickness of the pavement structure (Section 631). If a fill is not compacted, settlement will occur and base material may sink into the subgrade. Fills should be built in horizontal layers or lifts of not more than 12 inches in thickness for soil containing less than 25 percent rock larger than 6 inches. Lifts of 8 inches are preferable, if practicable. Otherwise, layers should not exceed 24 inches. Compaction specification given in Articles 106-3.5 and 106-3.4, FP 57 are good guides to follow. Also recommended is reference(12).

If compacting rollers are not used, the earthmoving equipment should be routed to cover the entire width of the fill layer. Side hill fills wider than the outside width of the tractor tracks should also be compacted in layers. A "shelf" is excavated at the toe of the fill and the fill built up on the shelf. This shelf may be built as the pioneer road for clearing and grubbing.

The ground surface should be prepared for the fill by removing humus and other weak soil, and by scarifying to provide a bond between the surface and the fill.

The subgrade in cut sections does not ordinarily need compaction. However, if the undisturbed soil density is less than design density, it should be scarified to a depth of about 6 inches and rolled. The surface of the subgrade should be bladed smooth before the base course is laid.

641.2 OPTIMUM MOISTURE CONTENT. Soil settles because air and water is expelled under compression. Moisture is required during compaction to lubricate the soil particles so they will slide into the air spaces. Too little moisture will leave air spaces; too much will leave water which will squeeze out under loading. The quantity of moisture which will enable a soil to be compacted to its maximum density by a standard method is termed "Optimum Moisture Content" (O.M.C.).

O.M.C. is determined in the soil mechanics laboratory by the standard AASHO test (ASTM D 598-58 T) or the modified AASHO test (ASTM D 1557-58 T)(4). These are commonly referred to as Proctor tests. The soil sample is compacted in a mold in layers, weighed, an oven sample dried, and wet and dry densities computed. The test is repeated at various moisture contents until a curve of dry density over m.c. can be plotted. The density at the top of the curve is the maximum density, and the m.c. at that point is the O.M.C. Compaction specifications are usually 90 to 95 percent of maximum density. (Article 106-35 FP 57)

642 CONTROL MEASURES

642.1 CONTROL OF MOISTURE CONTENT. To obtain the design density of subgrade requires control of the moisture content during compaction and check of the density of the compacted soil. Following are control methods which can be used in the field by the construction engineer with only a few items of testing equipment.

$$\text{Moisture content } \% = \frac{\text{wet weight - dry weight}}{\text{dry weight}} \; 100$$

Moisture content should be maintained within approximately ten percent of O.M.C. Samples for control of moisture in the construction area should be obtained several times daily. When the moisture content of the soil being worked is too low, water should be added at either the excavation area or where compaction is being accomplished. If the soil is too wet, measures should be taken to allow drying. This could take the form of adding dry material if it is available, loosening the soil by scarifying or other means to let air get at more exposed surface to speed drying, or reducing the thickness of the layers.

Sampling procedures:

1. Take a 15-20 gram or larger representative sample of material removed for density determination, seal in a moisture proof can, label and hold for later moisture determination. Drying is best accomplished by putting the opened can in an oven controlled to 105-110 degrees C. temperature until the sample reaches constant weight (preferably overnight). If an oven is not available, the soil can be dried in an open pan over low heat if the material is frequently stirred so as to prevent burning. To compute moisture content the necessary measurements are weight of can empty, weight of cap plus wet soil, and weight of can plus dry soil.

2. A method for obtaining moisture content in the field consists of burning off the moisture with alcohol. Weigh special cup, add 20 to 30 grams wet soil, reweigh, mix with enough alcohol to make a slurry of the consistency of heavy cream, ignite and burn off the alcohol, repeat mixing and burning twice more, and finally, weigh cup and dry soil.

642.2 CONTROL OF DENSITY. Densities obtained should be as close as possible to those determined in the pavement structure design. Field procedure for measuring density is as follows:

1. Select representative location in the area to be sampled.

2. Dig a hole 6-9" in diameter through the layer being compacted or approximately 6" deep for the sample, carefully saving all the material removed.

3. Weigh wet material removed and adjust to dry weight using the m.c. obtained for this sample hole.

4. Obtain the volume of the hole. This may be done by an adaptation of the sand-cone method (ASTM D 1556-58 T) by filling the hole with clean dry free-flowing sand from a measured volume and deducting the volume remaining. Another method of obtaining volume is to place a rubber balloon in the hole and fill it with water from a calibrated tube (p. 104(7/).

5. Compute the unit dry density in lbs. per cu. ft. by dividing the dry weight of the material removed by the volume of the hole. The "Pocket Pentrometer" (Article 622.2-5) is useful for quickly measuring degree of soil compaction at the surface of a subgrade. Gauges using radio-active material for rapid field determination of moisture content and density at any depth within 2 percent accuracy are available(8/).

650 SOILS IN DRAINAGE STRUCTURE DESIGN

650.1 DRAINAGE AND SOILS. Road Engineering includes the design of drainage structures to intercept, collect and remove water. Recognition of the properties of permeability and capillarity, and the drainage and frost action characteristics of soils, is important in the design of adequate drainage structures. Soil "Erosion Index" is valuable in determining culvert spacing. When the performance of culverts in existing roads is used as a guide for culvert design, differences in soils and their characteristics should be considered.

Runoff is affected by the porosity of the soil and the soil depth to the impervious layer. Culvert design methods generally used are based on the runoff from the drainage area. However, the formulas presently used for computing peak runoff based on rainfall intensity do not include any co-efficients which would account for differences in soils, or in vegetative cover. Design based on actual runoff records, when available, compensates for the influence of soil and vegetation.

650.2 CULVERT SPACING. One of the problems encountered by the forest road designer is the spacing of lateral drainage culverts. On hillsides where valleys which provide natural culvert sites are far apart, the standard ditch of a climbing road would overflow before the water collected from the hillside reaches a culvert. Intermediate cross drains are required to carry the water to the lower side of the road. The factors affecting the spacing of such cross drains are the gradient of the soil, rainfall intensity and area and character of the hillside above the road. One solution is to increase the size of the ditch. However, deep ditches are a hazard to traffic, and present maintenance problems. Wide ditches increase excavation costs out of proportion to the cost of cross drains.

A useful guide to lateral drainage culvert spacing is the table given in Article 650.3 published in reference(9/). It gives the maximum spacing in feet by road gradient percent and soil erosion index (Article 612.3). It is based on a 25 year maximum rainfall intensity of 1 to 2 inches per hour falling in a 15 minute period, and a road base of 20 ft. including a 1 ft. depth ditch.

650.3 CULVERT SPACING TABLE

Maximum Spacing in Feet of Lateral Drainage Culverts

Road Gradient in percent	Erosion Index 10	20	30	40	50	60	70	80	90	100
2	900	1225								
3	600	815	1070	1205						
4	450	610	800	905	1015					
5	360	490	640	725	810	865	1000			
6	300	410	535	605	675	720	835	1010		
7	255	350	455	515	580	620	715	865	1030	1210
8	225	305	400	450	505	540	625	755	900	1055
9	200	270	355	400	450	480	555	670	800	940
10	180	245	320	360	405	435	500	605	720	845
11	165	220	290	330	370	395	455	550	655	770
12	150	205	265	305	340	360	415	505	600	705
13	140	190	245	280	310	335	385	465	555	650
14	130	175	230	260	290	310	355	430	515	605
15	120	165	215	240	270	300	335	405	480	565
16	115	155	200	225	255	280	310	380	450	530
17	105	145	190	215	240	265	295	355	424	500
18	100	135	180	200	225	250	280	335	400	470

660 SOIL SURVEYS

661 INTRODUCTION

661.1 FACTORS GOVERNING SOIL SURVEY. The methods used in making a soil survey for a forest road project and the intensity of sampling will be governed by the following factors:

1. The standard, permanence and cost of the road. The greater the construction cost, the more expenditure justifiable for the soil survey.

2. The manpower, time and funds available for the survey.

3. The field equipment and laboratory facilities available.

4. The requirements of other forest management uses for the soils data obtained by the survey. (Such uses may include logging planning, silviculture, and erosion control). (See Forest Management Handbook II E "Forest and Soils" and 9/).

The procedures suggested below for soil surveys for roads are also applicable for soil surveys for such forest management purposes, with the addition of data on the humus layer and the soil horizons (9/).

661.2 ADVANCE INFORMATION TO COLLECT. The first step in the soil survey is to collect and study all available information on the geology and soils of the area. These may include the following:

1. U.S.G.S. Geologic Quadrangles

2. Oregon State Department of Geology and Mineral Industries Geologic Maps

3. U.S.D.A. Soil Survey maps (These are usually limited to the lower valleys)

4. Cruise maps and other topographic maps showing rock outcrops, landslides and swampy areas as well as land forms

5. Aerial photos which, in addition to features named in (4) may reveal soil variations by vegetative changes and the "tone" on the "gray scale "

6. If any roads have been built in the locality, examine the soils in the cuts and note their performance as materials of construction, including bank slopes and their stability, fill settlement, and erosion; pavement structure thickness and wear, and effectiveness of drainage structures

661.3 SOIL SURVEY TOOLS. Tools used for making soil surveys include the soil auger of 1½ inch diameter or larger, posthole digger, or pipe and pipe wrenches for bore holes; and shovel and pick for pits. A spoon or scoop is useful to remove material from holes. Sample bags are of canvas or heavy plastic (for retaining field moisture content of sample). A pack board is convenient for packing out sample bags. A carpenter's flexible steel rule is used to measure depths of soil layers.

Depth of soil to bed rock on steep ground slopes, where the rock is apt to be close to the surface, is best obtained with a 3/4 inch punch bar and maul or sledge. This information is essential before fitting a grade line on the road location profile.

662 SOIL PROFILE SURVEY

662.1 PURPOSE OF SOIL PROFILE. A soil profile along a road preliminary or location survey is a valuable guide to changes in grade line, or in alignment, to make use of the best soils available. The profile will show if soils from cuts will be suitable for fills or whether selected borrow will be required. The extent of organic soils and of rock, to be avoided, if possible, and the depth to rock on steep side slopes will be shown. The depth to water table will aid in design of drainage facilities. Combined with CBR tests of subgrade materials the thickness of pavement structure for various sections of the road can be determined.

662.2 SURVEY PROCEDURE. Data for plotting a soil profile are obtained, usually by making borings with a soil auger, at intervals along the road survey line. The auger handle is rotated enough turns to fill the threads, then withdrawn and the soil in the threads removed. When a change in the soil is detected, the depth is measured and recorded. Post holes or pits may be dug but require more time than auger borings. Holes are spaced at intervals which will give an accurate soil profile. The spacing will depend upon the variability of the soil profile. Particular attention is paid to high and low spots.

Borings should extend well below the proposed grade line in cuts, and 3 feet below the ground line in fills, or to the bottom of soft or mucky layers. Bridge abutment sites are bored to bed rock. The layers are identified in the field, if possible, or 2 lb. samples are taken for subsequent laboratory identification.

The depth to water table is obtained by observing the depth at which free water stands in the hole. This observation should preferably be made after 24 hours.

The data on each boring, including station, depth of each layer in the profile and soil group symbol of each layer if identified in the field, or a serial number, if the soil is to be identified in the laboratory, is recorded in the field book. The sample bag tag shows road identity, hole number, and soil layer serial number.

662.3 PLOTTING SOIL PROFILE. The ground line profile is plotted on a horizontal scale of 1 inch to 50 feet and a vertical scale of 1 inch to 5 feet. The limits of the various soil layers are plotted vertically at the station of each bore hole. These points are connected to give a profile of the layers. The water table depths are plotted and connected with a blue line.

663 SAMPLING FOR LABORATORY TEST

663.1 SAMPLING FOR CBR TEST. Samples large enough to yield 50 lbs. of material passing a No. 4 sieve are obtained for making CBR tests. The samples should be representative of the soil types which will be used in the construction of the subgrade.

663.2 SAMPLING BORROW PITS. Prospective borrow areas should be sampled with a grid pattern of pits or borings spaced sufficiently close to get an accurate plot of the soil profile. Either field identification, or 2# samples for lab analysis should be used for classifying soils in the profile. If the borrow material is to be used as selected sub-base material, 50# samples should be obtained from the desired layers.

663.3 SAMPLING ROCK PITS. The sample should be representative of all materials in the pit. Separate samples should be taken from layers that apparently differ. The size of sample should be at least 30#. Information accompanying sample should include:

1. Location of supply sketch and general description.
2. Approximate quantity of material available.
3. Estimate percent of useable material.
4. Amount and character of overburden.

5. Distance to road on which it is to be used.

663.4 SAMPLING SAND AND GRAVEL. Take a composite sample if layers do not differ radically. If layers do differ, take samples from various layers. A representative sample should be taken either from the face of a worked area or from an approximate depth of worked area. Size of sample: sand 20#; gravel 50#, or large enough to yield 50# gravel. Accompanying information same as for rock.

664 RECONNAISSANCE SOIL SURVEY

664.1 PURPOSES. The reconnaissance soil survey is made for one or more of the following purposes.

1. To ascertain which of alternate routes is preferable from the standpoint of the soils encountered. Particular attention is paid to indicators of potential slide areas; poorly drained areas and other trouble spots. Rock may be a help, as a source of surfacing aggregates, or a hindrance to construction.

2. As a guide to detailed road location and design along a selected route. Center line cut is influenced by soil as well as side slope.

3. For logging planning. Erosible soils call for protective measures, such as cable yarding instead of tractor, smaller clear cut areas, etc.

664.2 PROCEDURES. The reconnaissance soil survey starts with the study of all available information from maps and air photos (Article 661.2). Field work may vary from simply observing exposed soils to a less intensive modification of the soil profile survey procedure. Soil layers are examined where they are exposed in creek banks, other eroded areas and in the hollows left by the root wads of wind-thrown trees. Surface soils may be exposed with a shovel. The punch bar is used on steep side slopes. Soils are identified in the field, with samples being taken of doubtful soils. The relation between soil and land form, geology elevation, and vegetation is noted. Complete field notes are recorded.

If no line has been staked, the place where soil notes are taken is marked on a large scale map or photo with an identifying number corresponding to the number in the field book. In addition to soils, data on rock, gravel, swampy or ponded areas, drainage and any other factor affecting road location or design is noted.

670 LANDSLIDES

670.1 IDENTIFICATION OF SLIDE AREAS. The road engineer working in a locality where landslides are encountered should study Chapter 4, "Recognition and Identification of Landslides" and Chapter 5, "Airphoto Interpretation" in reference (10). He should also study available aerial photos of known slide areas. Among the indicators of slides observed in the Douglas-fir region are the following:

1. Leaning trees. Trees on slump landslides lean uphill on the upper portion of the slump and downhill near the toe. (Figure 44, reference 10/).

2. Tension cracks on the surface of the ground. (Figure 36, reference 10/).

3. Exposed soft clay strata on stream banks, and other areas devoid of trees.

4. Terraces or mounds at the base of steep slopes.

5. Differences in color tone on aerial photos. Wet areas are dark and dry areas light. Slides are often associated with seepage areas.

6. Alder and maple patches on side slopes, not in stream bottoms, are plant indicators of potential slide areas.

670.2 PREVENTION OF SLIDES. Slide areas are to be avoided in road location, if at all possible. If crossing a slide area is unavoidable, preventative measures can be taken in road construction. This subject is covered in Chapters 7 and 8, reference(10/). Some of the control measures adapted to forest roads are as follows:

1. Drainage of depressions above the road by intercepting ditches.

2. Benching the top of the cut slope or benching the cut bank. Removal of the trees above to reduce the weight on the earth mass.

3. Cribbing the fill slope on a steep hillside with logs on temporary roads, or bin-type metal or concrete retaining walls on permanent roads.

4. Stripping unstable fill foundations. Fill slump on weak foundation soil may be corrected by depositing rock or gravel as a counterweight on the opposite side from the slump. (This was done on the Smith River access road at the Harris ranch).

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CONTENTS

700 ROAD DESIGN

710 DESIGN OF PLAN AND PROFILE

711 INTRODUCTION

711.1 SCOPE OF DESIGN. Division 700 covers the office design of roads, including drainage structures. Chapter 710 covers the design of location line (L-line) alignment and gradient, based on a preliminary line (P-line) traverse. Section 712 gives the consecutive steps to follow in making a graphic design, using plotted cross-sections, templets, and BLM Road Design Form No. A1-254. Instructions are given in sufficient detail to enable the designed with no previous experience in this method to use it. One of the advantages of this method is that a relatively inexperienced road engineer can, by trial and revision, produce an acceptable design. This method is best adapted to situations where the designing can be left until inclement weather restricts the engineering party to the office.

Section 713 covers road design by the computed contour offset method by which offsets from P-line to L-line, and cuts and fills, are obtained by computation instead of graphically. It is a faster method saving time in the office but requires more experience in road engineering on the part of the designer. Section 714 treats briefly with the design of roads on a belt of large scale topography. This method is covered in detail in route survey textbooks.

Chapter 720 covers the design of drainage structures, with emphasis on culvert design. Hydrologic factors are discussed and instructions for determining the size of a culvert, by several methods are given.

Review of Chapter 330 "Considerations in Road Location" prior to designing is recommended.

711.2 PRELIMINARY LINE REQUIREMENTS. To obtain reliable results from design based on a P-line traverse, it is essential that the P-line be located so that it is reasonably close to the final L-line. For design methods Sections 712 and 713, the two lines should never be farther than 50 feet apart, and should average less than 30 feet apart. If any segment of the P-line exceeds these distances from the projected L-line, the segment should be re-traversed. For the design method given in Section 714, the two lines may be farther apart providing the contours are accurate. The field notes should show cross-sections at the crests of ridges, the bottoms of draws, and at intervals between such points not longer than 100 feet. If there is any doubt as to the direction at which cross-sections were taken at angle points, the designer should check with the note-keepers. Cross-sections should be taken along the bisector of the interior angle, at angle points, and perpendicular to the P-line at other points.

711.3 DESIGN STANDARDS. Before starting the design of a road the designer should obtain, from the policy-making authority, decisions on road class, maximum curvature and gradient, surfacing, culvert types, and any other proposed contract specifications relating to the road. Unless soil data are supplied from which the designer can determine bank slope ratios and thicknesses of pavement structure, decisions on these matters are also necessary. Review Chapter 330 "Considerations in Road Location."

711.4 SUBGRADE WIDTH. Bureau of Land Management road standards prescribe the surfaced width, and the pavement structure side slope ratio. The width of the subgrade will accordingly vary with the thickness of the pavement structure. The width must be known before design by the graphic method can be done. For determination of pavement structure thickness, see Section 631. If the first contract does not require completion of surfacing which is sometimes left to a subsequent contract, the subgrade width must be designed for the maximum thickness of rock that will eventually be placed on the road.

712 GRAPHIC DESIGN

712.1 ROAD TEMPLET. On a sheet of 10 x 10 cross-section paper, draw on a scale of 10 ft. to the inch, typical cross-sections for the subgrade widths and bank slope ratios required for the soils involved. The steepest cut banks which will be stable will reduce the area of raw earth exposed to erosion, and withdrawn from timber production. For a "side hill" section, draw back slope, ditch, subgrade width and fill slope. Mark the center line. For a through embankment section, widen the subgrade 2 ft. at each shoulder (for fills over 6 ft.) and draw bank slopes. Mark center line and 1 ft. widening points (for fills under 6 ft.)

Cut templets of the cross-sections from heavy-weight, transparent plastic. Mark them with subgrade width and bank slope ratios for ready reference for future use. Square the sides of the templet with the subgrade line to facilitate orientation in use.

712.2 PLOTTING PRELIMINARY LINE TRAVERSE. The most rapid method of plotting is with a drafting machine. Use one arm of the machine for the traverse courses, the other for drawing perpendiculars at points where cross-sections were taken. Set the 10-50 traverse scale so the 50 scale is on the upper side. Plotting 100 ft. to the inch, the 50 scale can be read direct to the nearest 2 ft. and interpolated to 1 ft. Use the 10 scale to check distances for gross errors. Use a needle point to prick traverse angle points. (A discarded dentist's probe, sharpened to a needle point, is the best tool for this purpose.) Enclose the point in a small circle and mark the station number. In drawing the traverse line between points, stop at the edge of the circle. Do not touch the pin point. Inking the P-line in red will avoid confusion with pencilled L-line tangents and loss in erasures of trial lines. To draw cross-section lines along bisectors at angle points, set the vernier half-way between traverse line bearings and draw bisector with the perpendicular arm. When starting plotting draw a true North reference line. Check back on it occasionally to ensure that the orientation of the machine has not been disturbed.

If traverse coordinates are computed, plot the angle points by coordinates. Electronic computation is particularly recommended for closed traverses and for right-of-way plats. A computer program is available which

FORM NO. A1-254
MAY 1955

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

ROAD DESIGN FORM

Project ______ No. ______ Sect. ______ Class ______ Page ______

District ______ Designed by ______ Date ______ 19 ___

"P" Station	"L" Station	Dist.	℄ Offset		Ground El. Projected ℄	Percent Grade	Tangent Grade El.	Ordinate	V.C. Elev.	Trial Grade El.	Contour Offset	S.B. Elev.
			Left	Right								

will balance the traverse for the error of closure and print out adjusted bearings and distances, and coordinates computed from them. To plot coordinates lay off 10 inch (1000 ft. to scale) squares, on detail paper, or a good quality pencil drawing paper. The engraving on cross-section paper is not precise enough for coordinate plotting. Use a beam compass swung in 3-4-5 ratio arcs to get lines truly perpendicular. Check the squares by measuring the diagonals, which should be equal. Coordinates may be plotted by drafting machine after the squares have been laid out, using the vertical arm for latitude and the horizontal arm for departure. Use the adjusting screw and a large triangle to set the scales truly perpendicular. Use a half-circle protractor to draw cross-section lines.

Plot all section corners and one-quarter corners to which the P-line was tied, and mark with standard symbols. Draw lines between corners, and land ownership subdivision lines, and mark ownerships. Draw streams and swamps in light blue pencil. Mark rock outcrops, and any other data from the field book which will aid in road design. Mark the side slope percent at each end of the cross-section line.

The above drawing, on which the alignment of the L-line will also be plotted, is termed the "hardshell".

712.3 PRELIMINARY LINE PROFILE. Plot the P-line profile on pencil profile drawing paper, horizontal scale 100 ft. to the inch, vertical scale 10 ft. to the inch. Mark grade control points, such as takeoff from existing road, takeoffs for spurs from road being designed, fills over culverts, cuts required for benching on steep side slopes, landings, crossings above or below rock outcrops, etc. Draw a trial grade line between these points, and compute percent of grade. If it appears, from inspection of the hardshell, that the L-line will be shorter than the P-line, keep the profile grade below the maximum permissable. For example, reduce a 10 percent grade 0.1 percent for each 1 percent of shorter length. At takeoffs and approaches to and exits from landings, allow adequate room for vertical curves, and for grade separation at takeoffs. (Article 712.5(10))

712.4 PLOTTING CROSS SECTIONS. Plot cross-sections for points at which side slopes were taken on 10 x 10 cross-section paper. The scale is the same as that of the road templet, usually 10 ft. to the inch both horizontal and vertical. Use a heavy vertical line as a center line, the heavy horizontal lines as even 10 ft. elevation lines, and plot actual ground elevation, to scale, on center line. Draw the ground side slopes. Mark P-line station and ground elevation in 0.1 inch high figures. Drawing successive cross-sections from the bottom of the sheet up will help the designer to visualize the topography. Study the cross-sections for control points, such as fills over culverts, or bench sections on side slopes steeper than fill bank slope, and mark them with a star or asterisk.

712.5 DESIGN OF ALIGNMENT. Following are the consecutive steps to follow in designing the alignment of the L-line, using Bureau of Land Management Road Design Form No. A1-254:

1. In "P Station" column enter all P-line stations at which cross-sections were taken.

2. In "Trial Grade El." column enter grade elevations, read from the P-line profile, to nearest 0.5 ft., for the stations in the "P Station" column.

3. On cross-section set road templet subgrade line at grade elevation, read from Design Form, and slide to left or right to get desired section. This may be a balanced section on moderate slopes, or a benched section on steep slopes.

4. In "Contour Offset" column enter horizontal distance in feet from P-line to road templet center line, as scaled from the cross-section plot. Mark control points with a star or asterisk.

5. Mark contour offset points on the cross-section lines on the hardshell. Ink these points in black to preserve them from erasures. Mark control points with star or asterisk.

6. Find stations of culverts on P-line profile. Find approximate size of culvert from the graph Figure 725-1. This requires knowing the drainage area above the culvert, obtained from a topographic map or aerial photo. On the cross-section find the offset to give sufficient fill at center line. Fill at shoulder on inlet side should be not less than 1 ft. above top of pipes up to 24 in. diameter, and half the diameter for larger pipes. Plot offset on hardshell.

7. Mark desirable turnout sites on hardshell, for single lane road. Turnouts are required on blind curves, and between where spacing exceeds specified maximum. Place the latter where they develop naturally from surplus excavation.

8. Plot trial L-line on hardshell. On moderate side slopes, say under 40 percent, draw tangents through contour offset points which are in line. Draw tangents to intersects at P.I.s and mark P.I. with a small triangle. Then connect the tangents with curves which, so far as possible, touch the contour offset points between tangents. The use of plastic curve templets (Figure 411-3) will facilitate curve fitting. In lining up offset points, give the greater weight to the control points. On steeper slopes, and sharp ridges and valleys, fit curves first. Then draw tangents connecting the curves. Be sure they are truly tangent to the curves. At turnouts keep L-line above offset point.

9. Study the trial L-line to see if the alignment can be improved. (Refer to the tables in Section 331 for the effect of alignment and gradient on truck travel time and cost.) Revise the L-line until the best alignment consistent with reasonable construction cost is obtained. Have the design inspected by your supervising engineer before proceeding with computation of alignment.

10. In taking off on a steeper grade from an existing road, particular care is needed to get grade separation and room for vertical curve. Before proceeding with stationing, plot the adjacent segment of the existing

road on hardshell and profile. Plot the profile of the first curve of the new road and draw the vertical curve. Check that the grade elevations on the new road are not higher than those of the existing road back of the grade separation point. (Article 423.5, Figure 423-2) It may be necessary to set starting Sta. 0+00 back to get sufficient takeoff room. Similar precautions should be taken with approaches to landings to allow room for vertical curves at each side of the truck space for loading. (Figure 423-3)

712.6 COMPUTING ALIGNMENT DATA. When, in the judgment of the designer and his supervising engineer, the L-line is the best that can be drawn at this stage in the design, proceed with the compilation of alignment data. Complete the design of a segment at a time, between major control points, to avoid wasting time on a segment beyond a segment which may have to be revised. Following are the consecutive steps in measurement and computation of alignment data:

1. Measure bearings of tangents. This is best done with the drafting machine. Mark the bearings on the tangent lines between curves.

2. Compute curve data: intersection angle Δ , semi-tangent "T", and length of curve "L". The precision of the compass traverse and plotting does not justify computing T and L closer than the nearest 1 ft. which can be done efficiently by slide rule.

3. Scale distances between P.I.s with 50 scale. (With the drafting machine this can be done coincident with measuring the bearings.) Compute the station of each P.I., P.C. and P.T. and mark along radii lines drawn from P.C. and P.T. Note that cumulative stationing of the L-line is along the curves, not the semi-tangents.

4. From the nearest numbered station scale the distance to the point where a cross-section line intersects the L-line, and compute L-line station. Enter in the "L Station" column on the Design Form, on the line with the corresponding P station.

5. Scale the offsets from P-line to L-line at each of the tabulated stations and enter in "℄ Offset-Left-Right" column.

712.7 LOCATION LINE PROFILE. Following are the consecutive steps in obtaining L-line ground elevations and plotting the profile:

1. On each cross-section draw the L-line center line at the offset distance from the P-line. Print the L station in 0.2 in. high figures.

2. Read the L-line center line ground elevation, and enter in "Ground El. Projected ℄" column.

3. Plot L-line profile, by plotting ground elevation over L station and connecting these points with a free hand ground line.

4. Plot a few key trial grade elevation points. Using these points as a guide, fit a grade line to the profile. If the grade line

coincides closely with balanced trial grade elevations, close to a balanced design should result. Enter station of each grade break point (V.P.I.) and its elevation in "Percent Grade" column. Compute percent grade between each adjacent V.P.I.s and enter in "Percent Grade" column and on grade line on profile.

5. Compute grade elevation for each L-line station tabulated in the "L-Station" column, and enter in "Tangent Grade El." column.

6. Where vertical curves are needed, decide on the length of vertical curve which will best fit the profile. Find vertical curve ordinates in Calders' Table 10 for 200 ft. and 300 ft. length vertical curves. (1/) Compute ordinates for other lengths. Enter in "Ordinate" column on Design Form. Compute "V.C. Elev." column by adding ordinate (concave V.C.) or subtracting ordinate (convex V.C.) to or from elevation in "Tangent Grade El." column.

712.8 EARTHWORK MEASUREMENT. The remaining stage in design is to plot L-line cross-sections and compute quantities of earthwork in excavation and embankment. Following are the consecutive steps:

1. On each P-line cross-section mark the grade elevation of the L-line taken from the Design Form.

2. Lay templet at grade elevation and center line. Slide horizontally for widening for curves, turnouts, and fills. Widen inside shoulder of curve a distance in feet equal to 0.07 x Degree of curve, or 400 ft./radius. If designing a two-lane road with superelevated curves, plot the superelevated sections. Superelevation is not recommended for single lane roads. Widen fills if not already done with embankment templet. Draw bank slopes to complete L cross-sections.

3. Planimeter or compute end areas. Electronic computation of end areas, and of yardage, is the most economical method. (Article 512.3)

4. If end areas are planimetered, compute the cubic yards of earthwork in excavation and in embankment. Use a table of cubic yards per station for double end areas, found in most route survey textbooks. Add adjacent end areas, find cubic yards per station in the table, and multiply by the distance between sections <u>in stations</u>, to the nearest 0.01 sta. or 1 ft. In going from cut to fill sections, estimate the length of the pyramid and compute cubic yards from End Area x Length/81. Use Bureau of Land Management Form No. Al-255 "Earthwork Quantity Sheet" for hand computation.

5. Adjust embankment yardage for shrinkage of earth or swell of rock. Increase earth embankment yardage by the percent of shrinkage to get the yardage that will have to be excavated in order to make the fill. Shrinkage is affected by the following variables, in the manner tabulated:

Variable	Low Shrinkage	High Shrinkage
Soil	Good subgrade	Poor subgrade (Article 612.3)
Moisture content	Dry	Wet
Stumps	Small	Large
Fill height	High fills	Low fills
Fill foundation	Incompressible	Compressible
Equipment	Carry scraper	Bulldozer

Shrinkage will vary from 10 percent under the best conditions to 40 percent or more. Generally bulldozer construction in Western Oregon will average 25 or 30 percent shrinkage in common earth. Local experience is the best guide to follow.

The swell of rock depends upon whether the rock is solid or loose, the size of the fragments, whether ripped or blasted, and care in blasting. Usually rock from road excavations is used in the pavement structure, not in embankments.

6. If a balanced design is sought, compute mass and balance points in the conventional way given in route survey textbooks. Mark the quantities of free-haul excavation, overhaul excavation and borrow on the profile. Balanced design is generally suitable only for a road to be graded by scraper, or under a road construction contract with payments on the basis of yardage and overhaul, or bulldozer grading on moderate side slopes. For bulldozer grading on steep slopes, the following procedure is suggested. Mark on the L-line profile cubic yards of excavation and of embankment for each segment between cross-sections. Total the yardage in each fill. Mark in red the economical limit if bulldozer haul (Table 332-2) adjacent to fill. Total the excavation yardage within this limit. If embankment exceeds excavation, mark borrow yardage. Total the waste yardage in the segments outside the haul limit.

7. Study the profile in conjunction with the plan to see if any revision in grade line or in alignment can be made to improve the location or balance quantities. Excavation yardage may be decreased by raising grade line, sharpening curves on ridges or shifting alignment down hill to lower ground line. Embankment yardage may be decreased by lowering the grade line, sharpening curves in valleys, or raising the ground line by shifting uphill. If increase in either one is indicated, it may best be accomplished by straightening alignment or flattening curves. Revise the design until the best possible balance has been achieved, not only in earthwork, but also in truck travel time and road construction cost. The steps in Articles 712.6 through 712.8 should be carried out a segment at a time, between major control points, or for about 15 stations, before the next segment is designed.

713 COMPUTED DESIGN

713.1 COMPUTED CONTOUR OFFSET DESIGN. When the time available for design does not permit drawing cross-sections, L-line offsets and ground elevations may be computed, instead of being obtained graphically. The same P-line field data are required. For satisfactory design results the P-line should be surveyed close to the location route. The P-line traverse and profile are plotted in the same way as for graphic design.(Articles 712.2-712.3) The P-line stations and their ground elevations are entered in the first two columns of the Design Form, Figure 713-1. Grade elevations and grade percent, read from the profile, are entered in third and fourth columns. P-line cuts and fills are computed from differences between ground and grade elevations, and entered in "P-line-C-F" column. Slope percent is entered in the next column from the field book. The offset to the grade contour is computed by the formula:

$$\text{Contour offset} = \frac{\text{P-line C or F}}{\text{Slope \%}}$$

The computed offsets are entered in the "Contour Offset-L-R" column.

713.2 LOCATION LINE. The grade contour points are plotted on the hardshell by scaling the computed contour offsets along the cross-section lines from the P-line. These points outline a grade contour, which would be the center line of a balanced side hill cut-and-fill section, or the outer edge of a full bench section. Plot optimum center line points, taking into consideration the desired center line cut on steep slopes, and the required fill over culverts. (Article 712.5(6)) The distance from the grade contour point to the center line point is computed by the same formula as the contour offset. Fit a trial L-line to the center line points in the same way as given in Article 712.5(8). Scale the L-line stations, and enter in "L-line Sta." column. Scale the distances from the P-line to the L-line and enter in "L-line Offset-L-R" column. Compute the L line cut or fill, to be entered in the "Calc. L-line-C-F" column, by the following formula:

$$\text{L-line C or F} = \text{P-line C or F} \pm (\text{L-line offset x slope \%})$$

The sign of the term (L-line offset x slope %) is positive if the L-line station is above the P-line station in elevation; negative if below. Grade percent is corrected for any difference in length between P-line and L-line and entered in "G%" column. The L-line ground line is plotted on the profile by scaling the L-line cut or fill from the grade line. Vertical curve ordinates are entered in the "V.C. Ord." column, and applied to the L-line cut or fill to complete the "Corrected-C-F-" column.

To keep the L-line stationing as close as possible to the P-line stationing, equations are used, generally at the P.T. of a curve. A sample of contour offset location of a segment of road is shown in Figure 713-2 Plan and Figure 713-3 Profile.

714 TOPOGRAPHIC DESIGN

714.1 DESIGN ON PRELIMINARY TOPOGRAPHIC MAP. The logging engineer's modification of the highway engineer's method produces a belt of large scale topography along the P-line. The map scale is usually 100 ft. to the inch with 5 ft. contour interval. The belt width embraces the possible limits of the L-line. If contours are drawn in the field (Article 522.4) they are traced on the hardshell. If the contour distances from the P-line are computed electronically (Article 512.3), the contour points are plotted on the hardshell and connecting contour lines drawn. Control points are selected, the distance between them measured and the grade percent computed. A grade contour is stepped off along the contours in the same way as described in Section 41', "Route Projection on Large Scale Maps." Optimum center line points for desired cut or fill are plotted. (Article 712.5(6)) A trial L-line is fitted to the center line points. (Article 712.5(8))

A trial L-line profile is plotted by stepping off stations along the L-line with dividers, and reading ground elevations by interpolation by eye. The designer accustomed to reading a slide rule can estimate one-fifth of the distance between contours, and thus read elevations to the nearest foot. A trial grade line is drawn. The L-line alignment is revised as indicated by the trial profile, and the revision profile plotted. For yardage

FIGURE 713-1 DESIGN FORM - CONTOUR OFFSET ROAD

P-Line Sta.	Ground Elev.	Grade Elev.	G %	P-Line C	P-Line F	Slope L	Slope R	Contour Offset L	Contour Offset R	L-Line Sta.	Point	L-Line Offset L	L-Line Offset R	Calc. L-Line C	Calc. L-Line F	G %	VC Ord.	*Corrected C	*Corrected F
24	724.0	724.0	↑	0.	0.	-40	+40	0		24		0	0	0	0	↑			
+50	22.5	21.0		1.5		-50		3		+50		0	0	1.5		+6.6%		1.8	
23	17.0	18.0			1.0		+50		2	23			4	1.0				1.5	
										=22+78 Ah 22+67 BK						—			
+50	12.6	15.0	+6.0%		2.4		+40 +20+30		6	22+39	PT		10	1.6					
22	09.0	12.0			3.0		15+20		15	+96	PI		22	1.8					
+50	07.5	09.0			1.5		+30		5	+94 +52	20°R		7	0.7		+6.0%			
										+17	PC								
21	07.0	06.0		1.0		-40		2.5		21		1		0.6					
+50	06.5	03.0		3.5		-35				+50		7		1.1					
20	703.9	700.0	↓	3.9		-30				20		13		0	0	↓			

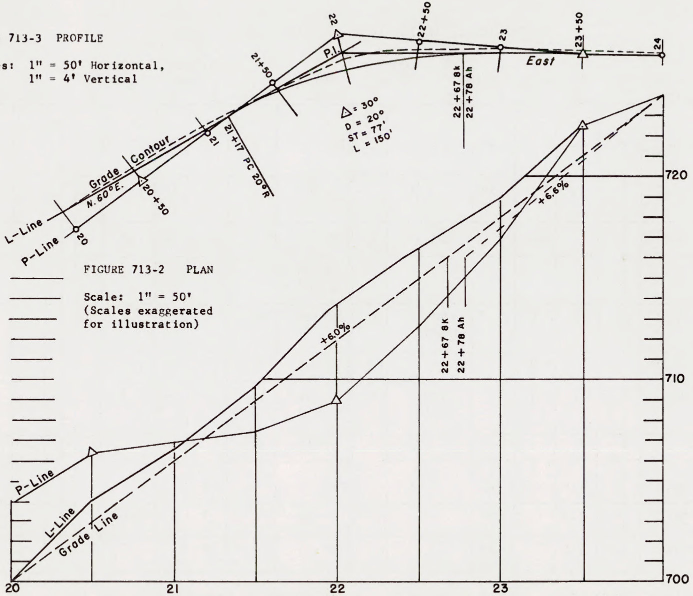
*Corrected for Vertical Curve or for change in grade due to difference in lengths of P-line and L-line.

FIGURE 713-3 PROFILE

Scales: 1" = 50' Horizontal,
1" = 4' Vertical

FIGURE 713-2 PLAN

Scale: 1" = 50'
(Scales exaggerated
for illustration)



computations cross-sections are read from the contours. Design procedure is otherwise as given in Articles 712.6-712.8.

715 ELECTRONIC DESIGN

715.1 BPR PROGRAMS. The Bureau of Public Roads, Region 8, has developed highway design programs for use with the IBM 650 Electronic Computer. Some of the programs are outlined briefly to show what steps in road design can be electronically computed. The facilities of the Bureau of Public Roads are available to the Bureau of Land Management engineers through the State Supervisor.

1. Traverse and coordinate. Computes course latitudes and departures and coordinates of angle points.

2. Slope topography conversion. Converts slope readings to difference in elevation at a horizontal distance.

3. Contour interpolation. Using output cards from program 2, gives distance from center line to each contour.

4. Horizontal alignment. From scaled coordinates of P.I.s and specified degree of curve, computes all curve data and stations and coordinates of all curve points, including spirals if wanted.

5. Offset of topography. From scaled offsets from P-line to L-line, and L-line stations, puts out new topography cards referenced to L-line. Also used for revised L-line from first L-line.

6. Ground profile. Using cards from program 5, gives ground elevations of L-line center line.

7. Design data check. Reveals major errors in data and where located.

8. Profile grade. Gives grade elevation at each L-line station.

9. Templet simulation. Gives templet cards for either coordinates of slope point or slope ratio.

10. Design earthwork. Using output cards from programs 5 and 9, gives earthwork volumes, mass ordinates, and slope stake fractions.

11. Updated design. Gives new volumes and mass for change in line or grade.

12. Design clearing. Gives distances out to clearing line and acreages.

716 PLAN AND PROFILE TRACING

After the culverts have been designed (Chapter 720) and culvert type, diameter and length marked on the profile, trace the plan and the profile on standard plan and profile tracing sheets. Draft a title sheet giving complete legal description of the lands crossed by the road, Bureau of Land Management number, names of surveyor and designer, field book numbers, and compass declination used in traversing. A specification sheet illustrating construction specifications will be helpful in getting the road built to design. Sample stake and reference markings are also shown.

720 DESIGN OF DRAINAGE STRUCTURES

721 INTRODUCTION

721.1 IMPORTANCE OF DRAINAGE. The engineering properties and characteristics of most soils are adversely affected by an increase in moisture content. (Section 612) Subgrades are weakened, surfaces and banks eroded, and slides triggered by an excess of water. Provision of adequate drainage is of paramount importance in road design. The drainage system must serve the function of intercepting, collecting and removing surface and sub-surface water. Many drainage problems can be avoided in the location of the road. Drainage should be a concomitant consideration with alignment and gradient.

721.2 TYPES OF DRAINAGE AND STRUCTURES.

1. Surface drainage. Surface water includes stream flow, runoff from the surface of the area above the road, and water falling on the road surfacing. Surface drainage structures used on permanent roads include ditches along the road, intercepting ditches above the road, culverts and cross-drains. Crowning is used to drain the road surface. (Article 631.2) On temporary summer roads, drainage may be limited to outsloping and dips. Bridges and fords are also classed as drainage structures, since the waterway size is a factor in bridge design.

2. Subsurface drainage. Subsurface water is infiltrated surface water which may appear as seepage, springs, high water table, or capillary water. Subsurface water is often associated with slides. Disposal of subsurface water is difficult and costly, requiring subdrains of perforated or porous pipe laid in trenches. The effect of subsurface water on the subgrade may be reduced by such measures as a sand blanket as a subbase, or as a layer in the subgrade, if subgrade soils are of high capillarity or frost action. (Section 612)

721.3 BASIS OF DESIGN. The design of drainage structures is based on the sciences of hydraulics and hydrology. Hydraulics deals with the flow of water. The capacity of a drainage structure can be computed quite accurately by an applicable empirical formula. Hydrology deals with precipitation and runoff. Methods of estimating the runoff from a given drainage area have been developed which are useful as a guide. However, because of the many variables involved, some of which are not considered in runoff formulas, any computation of peak discharge is an estimate. The final decision on the size culvert is a matter of engineering judgment. However, the designer should base his judgment on all available aids, and not substitute guessing for engineering. The culvert designer is often faced with the problem of finding a balance between over-designing, which would be uneconomical, and under-designing, which would result in failure. He sometimes takes a calculated risk. He considers how disastrous would be the consequences of failure, and the cost of repairing the road, as compared with the cost of a larger culvert. For example, a high fill, which would take many days to replace, is a greater risk than a low fill which could be quickly repaired. The down-stream damage from the washout would also have to be considered.

722 HYDROLOGIC FACTORS

722.1 PRECIPITATION. The estimate of peak discharge is based, first, on rainfall records and snow melt. Following are relevant rainfall factors:

1. Intensity, the amount of rain falling in a given period of time. The maximum number of inches falling in one hour is usually used as design intensity.

2. Duration, the length of time the rainfall continues. After watershed soil becomes saturated, additional rain drains off as it falls.

3. Frequency, how often the design maximum may be expected to occur. Design frequency is based on the life of the road, traffic, and consequences of failure. Frequency periods of 50 or 100 years are used for primary highways, and 25 years for secondary roads. For forest roads, frequency periods used are 10 to 25 years. The isohyetal map on page 8, reference (2/), shows 25 year period 60 minute rainfall intensity for Western Oregon to be as follows: Willamette Valley, Medford 1.10 in., Coast Range 1.25 in., west slope Cascades 1.30 in., Coos and Curry counties 1.40 to 1.60 in. The combined effect of snow melt and rainfall must be determined from local experience, or gauged runoff data.

722.2 RUNOFF. The runoff of a given rainfall from a drainage area is affected by the following factors:

1. The size of drainage area. The larger the area, the greater the volume of runoff. Drainage area in acres, taken from topographic maps or aerial photos, is generally used in runoff formulas or charts.

2. Topography. Runoff increases with steepness of slope. Coefficients used in runoff formulas are based on slope and character of topography.

3. Soil. Runoff varies with permeability or infiltration rate of the soil. However, runoff formulas do not take soil into account. Erosion Index is used in determining lateral drainage culvert spacing. (Article 650.3)

4. Vegetative cover. No reference is presently available for applying a coefficient for cover. From studies made in the Rocky Mountains it is estimated that clear-cutting a forested drainage area will increase runoff about 30 percent the first year. Runoff decreases as the clear cut is revegetated. Apparently, differences in type of vegetation, as forest or brush, do not make an appreciable difference in runoff.

722.3 SOURCES OF HYDROLOGIC DATA. Meteorological data are obtainable from the Weather Bureau, and from local agencies maintaining rain gauges, such as forestry and municipal watershed stations. Runoff data are obtainable from the U. S. Geological Survey and other agencies maintaining stream flow gauging stations, such as power companies, P.U.D.s and municipal water departments. The new U.S.G.S. report on flood magnitude and frequency in Part 14 (Western Oregon and Lower Columbia River) and the map of average annual runoff 1930-1957, when published will be valuable guides for designers.

723 DITCH DESIGN

723.1 ROADSIDE DITCH. The standard earth roadside ditch for Bureau of Land Management roads is a triangular section 1 ft. deep, 3 ft. wide on the roadway side, and 3/4 ft. or 1 ft. wide on the cut side, depending upon the bank slope ratio. The area of the ditch cross-section is thus 1.9 to 2.0 sq. ft. If surfacing depth does not give sufficient waterway area, additional ditching by blasting is required. The minimum ditch gradient should never be less than 0.5 percent, with 2.0 percent minimum to be preferred.

A ditch of larger cross-section may be required for draining ponded depressions, springs or swamps above the road, as well as rainfall. A ditch may need to be deepened to drain weak subgrade soil or a high water table. The size of ditch required may be computed from Manning's formula, $Q = A \frac{1.486}{n} R^{2/3} S^{\frac{1}{2}}$ where Q is discharge in cubic feet per second (c.f.s.), A is cross-section area in sq. ft., R is hydraulic radius in feet, S is slope in feet per foot, and n is coefficient for roughness varying from 0.025 for smooth ditches in good condition to 0.04 for rough ditches in poor condition. Hydraulic radius is area A divided by the wetted perimeter of the ditch. For example, given A of 2 sq. ft., wetted perimeter, ditch running full, 4.9 ft. Then R = 2/4.9 = 0.436. S is 10 percent or 0.1 ft. per ft. n is 0.04. Then $Q = (2)(1.486/0.04)(0.436^{2/3})(0.1^{\frac{1}{2}}) = 13.5$ c.f.s. The same ditch on a 7 percent grade would discharge 11.3 c.f.s. Since Q in c.f.s. is a product of area A in sq.ft. and velocity V in feet per second (f.p.s.) V = Q / A. Then the velocity on the 10 percent grade is 13.5/2 or 6.75 f.p.s., and on the 7 percent grade 11.3/2 or 5.65 f.p.s.

723.2 INTERCEPTING DITCH. As an alternative to a larger roadside ditch or frequent cross drains, an intercepting ditch above the road, to reduce the quantity of water reaching the roadside ditch, may be indicated. The intercepting ditch is built above the top of the back slope, following a gentle grade contour to the nearest valley above a culvert. It can be built with two passes of a small angledozer with tilting blade. The ditch gradient depends upon the soil, to avoid either silting or erosion.

724 CULVERT DESIGN

724.1 CULVERT TYPES. Following are the culvert types used on permanent forest roads, and the conditions under which they are customarily used:

Corrugated Metal Pipe (CMP)	- All conditions except those noted below.
CMP Paved Invert	- Water carries sediments erosive to metal.
CM Pipe-Arch	- Low fills, limited head room.
Multiplate	- Large sizes, over say 72 in. diameter
Reinforced Concrete Pipe (RCP)	- Corrosive soil or water, as salt water. Short haul from plant. Unloading and placing equipment.
Reinforced Concrete Box	- Extra large waterway. Migratory fish way.

The use of flared entrance or a wing wall and apron will increase the efficiency of a culvert, and sometimes permit the use of a smaller diameter. Pre-fabricated flared units are available for CMP. A projecting entrance roof of one-third the culvert diameter, projecting for half the diameter, will increase capacity. There is no hydraulic advantage in bevel or skew cuts on culvert ends. However, there is a cost advantage in saving material, with large culverts.

If the material is available near by, cedar log-and-puncheon culverts may be more economical for temporary roads.

724.2 INTRODUCTION TO DESIGN METHODS. Three general methods are used in determining the diameter of pipe culverts, or the size of pipe-arches. The first two are empirical methods: (1) from experience with existing culverts in the same watershed, or in similar drainages in the locality, (2) by a formula such as Talbot's which gives culvert waterway area or diameter directly for a given drainage area, rainfall intensity and coefficient for topography. The third method is by hydraulic design. After the design peak discharge is estimated, the size culvert for the given hydraulic conditions is computed, or read from charts. Peak discharge is estimated from: (a) drainage area, rainfall and coefficient for topography, (b) stream flow measurement.

The methods used in computing culvert diameter depends upon the conditions of flow. The following are recommended as being the most convenient for use in the design of CMP culverts for forest roads: (1) Armco Table 26-2 for culverts with free outfall and headwater at the top of the pipe. (2) California Highways Chart B, for culverts running full under head. (3) Herr's B.P.R. charts, for all culvert conditions. Instructions in the use of the methods named are given in ensuing sections.

725 EMPIRICAL DESIGN OF CULVERTS

725.1 EXPERIENCE WITH EXISTING CULVERTS. If there is an existing road in the watershed, examination of the performance of existing culverts may be the best guide to the determination of the sizes needed for the road being designed. If the new road crosses the same stream or valley, the size needed will be readily apparent. If no parallel road exists, inspection of culverts in localities where conditions of rainfall, topography, soil and vegetation are comparable will be helpful. In making the inspection, note the diameter, length and slope of the culvert. Note the height of flood water marks with reference to the culvert inlet. If the culvert has never run full, note the high water marks in the pipe and measure the waterway area. Note any erosion at the outlet, due to high exit velocity, or any fill damage. Note any siltation of the culvert, due to low velocity. Note the size and character of the drainage area, compute culvert size by the methods proposed to be used in design, and compare with the size actually used, or needed, as revealed by the inspection.

The number of years the existing culvert has been in use should be taken into consideration. Perhaps it has not been subjected to a peak flood, such as can be expected to occur during the life of the road being designed. If possible existing culverts should be inspected both at high water during the spring, and at low water during the summer.

752.2 TALBOT FORMULA MODIFIED. The Talbot formula is widely used. The original Talbot formula, $A = C\ M^{3/4}$, where A is culvert waterway area in square feet, C is a coefficient, and M is drainage area in acres, is for a maximum intensity of rainfall of 4 in. per hour. For use in Western Oregon this formula gives culvert sizes which are too large. The graph, Figure 725-1, gives culvert diameters computed by the author from the Talbot formula adjusted for rainfall intensities of 1 in, 1.25 in. and 1.5 in. per hour, and coefficients "C" of 1.0 for steep, rocky ground and abrupt slopes; 0.8 for rough hilly ground, steep slopes; 0.6 rough, hilly ground, moderate slopes. Where a horizontal line of drainage area in acres intersects a diagonal line of combined rainfall intensity and coefficient, find the culvert diameter needed on the vertical line. Note that the line of 1 in. rainfall and "C" of 1.0 coincides with the line of 1.25 in. rainfall and "C" of 0.8. Note that the Talbot formula does not take hydraulics of the pipe into account.

726 HYDRAULIC DESIGN OF CULVERTS

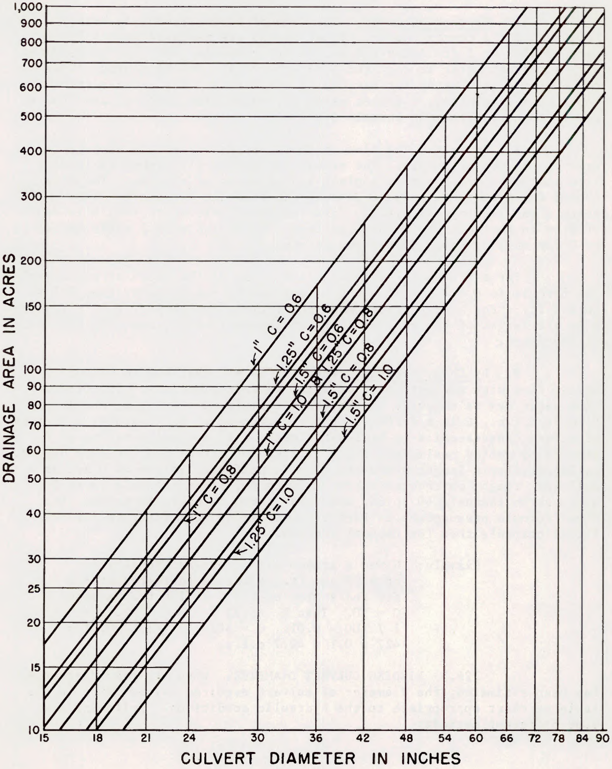
726.1 METHODS OF ESTIMATING RUNOFF.

1. Local Hydrologic Data. Local data on rainfall and runoff, if kept for a long enough period of years to embrace the design frequency, are the best guides for estimating design discharge. Drainage area is best obtained from a large scale topographic map, if available; otherwise, from aerial photos. Major drainages may be measured on U.S.G.S. quadrangles, but the scale is too small for minor drainages. Plot the traverse on the large scale map. On photos plot the corner ties and identifiable control points, and draw the road freehand between these points. Outline the boundaries of the drainage areas. Planimeter areas or get acreages with transparent dot-grid. Adjust for scale distortion on aerial photos. (Section 412)

2. Herr's B.P.R. charts. In the absence of local data, using the data given on pages 7 and 8 of "A Simplified Method for the Hydraulic Design of Culverts" by Lester A. Herr, Bureau of Public Roads (2/) is the best present method of estimating peak discharge. From the map on page 8 find the rainfall intensity for the locality. From the chart of K-factors find the K-factor to use opposite rainfall intensity and under the appropriate topography. The Roseburg district engineers use the K-factor found under "Rough-Hilly 15%-30%"

FIG. 725-1 CULVERT DIAMETER FOR DRAINAGE AREA BY TALBOT FORMULA MODIFIED

FOR RAINFALL INTENSITIES OF 1, 1.25 & 1.5 INCHES PER HOUR AND COEFFICIENTS "C" OF 0.6, 0.8 & 1.0



for mountainous slopes over 30 percent. They have checked culverts in use for 10 years with the Herr charts, and found the smaller K-factor to be preferable. On the graph on page 7 find the intersection of the vertical line from drainage area with the diagonal line of K-factor, and read discharge in c.f.s. horizontally to the left.

726.2 MEASUREMENT OF STREAM FLOW.

1. By current meter. The flow of large streams is best measured with a current meter. Water depths are measured with a level rod, usually at 5 ft. intervals across the channel. Velocity is measured with a current meter at each rod position and at several depths. Time is taken with a stop watch for periods of one minute. The cross-section of the stream is plotted, the area measured, velocities computed and flow in c.f.s. computed from the formula $Q = A\ V$.

2. By weir. The flow of small, rocky streams is best measured by the use of a weir. The stream is temporarily damned so it will flow through a notch cut in a plank at the crest of the dam. The discharge for a rectangular weir is computed from the formula $Q = 3.39\ L\ H^{3/2}$ where Q is discharge in c.f.s., L is length of weir notch, and H is depth of flow in the weir notch, both in feet. ARMCO Table 45-2 gives values of Q for various notch depths and lengths.

For a triangular weir with the sides of the notch at right angles the formula is $Q = 2.5\ H^{5/2}$ where H is depth of notch, range from 0.1 ft. to 2.0 ft. For a trapezoidal weir the formula is $Q = 3.37\ B\ H^{3/2}$, where B is the length of the bottom of the trapezoidal notch, and H is the depth of the notch.

3. By Chezy formula. Where it is not feasible to measure stream flow with current meter or weir, an approximation of the flow at high water may be computed by the Chezy formula, $Q = CA\sqrt{RS}$, where Q is flow in c.f.s., C is a coefficient for roughness of the channel, A is area of stream cross-section to high water mark, R is hydraulic radius or A divided by wetted perimeter, and S is slope of stream bed, or drop divided by length, for a length where the flow is uniform. Values of C are as follows: rough, obstructed channels 30 to 40, stone channels 35 to 50, stony earth channels 40 to 60, and clean earth channels 60 to 80. The Chezy formula presupposes uniform flow, so it is more accurate for artificial channels than for natural streams.

Example: Given a stream with cross-sectional area of 8.55 sq. ft., a wetted perimeter of 8.4 ft. and a drop of 1 ft. in 100 ft. Assumed $C = 50$. Then $R = 8.55 / 8.4 = 1.02$, $S = 1 / 100 = 0.01$. $Q = 50 \times 8.55\sqrt{1.02 \times 0.01} = 427 \times 0.1 = 42.7$ c.f.s.

726.3 FINDING CULVERT DIAMETER. When the peak discharge has been estimated, the diameter of culvert required may be found in the table or chart appropriate to the hydraulic conditions. Following are four different methods:

1. By ARMCO Table 26-2. Where the outlet invert will be above the tail-water elevation, so there will be a free outfall of water, find the CMP culvert diameter in ARMCO Table 26-2, page 230 (3/) entitled "Capacity of culverts with free outlet, with water surface at inlet same elevation as top of pipe, outlet unsubmerged." The following extract from Table 26-2 shows the maximum discharge and the "critical slope" at which the maximum is reached. Increasing the slope beyond the critical slope does not increase discharge. Slopes less than the critical decrease discharge.

Diam"	Max. cfs	Crit %	Diam"	Max. cfs	Crit %	Diam"	Max. cfs	Crit %
15	4.6	1.8	30	26	1.6	54	110	1.0
18	7.1	1.6	36	40	1.2	60	150	1.2
21	11	1.8	42	59	1.2	66	190	1.2
24	15	1.4	48	83	1.4	72	230	1.0

2. California Culvert Practice Chart B. For culverts running full under head with outlet submerged, Chart B, an insert in California Culvert Practice (5/) affords a convenient method of finding the required culvert diameter. Instructions for use of the chart, and for checking that the entrance head exceeds the velocity head and entrance loss, are given in the reference.

3. By Herr's B.P.R. Charts. The use of the charts (2/) is recommended as the most accurate method for any condition. This publication is available in all Bureau of Land Management engineering offices. Explicit instructions in how to use the charts are given, together with four design examples. Conscientious study of the text and examples will facilitate the use of Herr's charts.

4. Concrete pipe culvert design. For the design of concrete pipe culverts use references (5/) and (6/). These books are usually available to engineers gratis from local concrete pipe manufacturers who are members of the American Concrete Pipe Association.

727 CULVERT DESIGN PROCEDURE

727.1 DATA TO ASSEMBLE. Before starting to design the culverts for a road, assemble the following data:

1. Field books. For small drainages field notes should show cross-section notes or side slopes at proposed culvert site, elevation of high water marks, and channel bed soil. For large drainages or streams field notes should show cross-section of stream to high water marks, profile of stream bed, bed and bank soils, drift and debris conditions. Also stream flow measurements, if made and fill materials available.

2. From profile. Station of culvert. Ground and grade elevations.

3. From local sources. Hydrologic data. Data on existing culverts. (Article 725.1)

4. From policy making authority. Types of culverts, life of road, period of years to be used as basis for peak discharge, fill compaction specifications.

5. Topographic map or aerial photos.

6. Culvert design reference books and cost data. Culvert spacing table. (Article 650.3)

727.2 CONSECUTIVE STEPS IN DESIGN. The following design procedure is suggested for designing culverts in draws or stream channels, other than the minimum 15-18 inch diameters:

1. Measure drainage area in acres. See Article 726.1(1).

2. Estimate peak discharge for number of years basis. If stream flow measurements were made, check with drainage area runoff.

3. Plot cross-section of ground at culvert site or profile of stream bed on cross-section paper. Plot cross-section of embankment. A scale of 5 ft. to the inch, both horizontally and vertically, is recommended.

4. Determine the best location for the culvert. Consider the alternatives of bottom location on line and profile of natural channel; modified bottom location if the channel is skewed from the normal center line; or a location to one side of the channel. (Articles 833.1 and 833.2)

5. Where a steep side slope would necessitate an uneconomically long culvert, with high exit velocity, consider the possibility of either skewing the culvert to discharge on the ground to one side of the channel, or installing a "cannon" culvert normal to the center line, at or near to the critical slope, discharging into a "splash pan" or spillway, or on rock rip-rap. (Article 833.1(1)) If a skewed culvert is decided upon, draw a cross-section along the skew line.

6. Draw the culvert invert line. Project far enough beyond fill toe to avoid any chance of blocking the culvert by sloughing of the embankment. This will depend upon the compaction to be required in the fill. Less projection is needed for compacted fills than for uncompacted. If the fill foundation soils are such that sinking under the weight of the fill may be expected, provide for camber in the culvert invert line. Scale culvert length and compute culvert slope percent.

7. Determine the permissable depth of headwater pool and plot. If the outlet will be submerged, plot the tailwater depth.

8. Find culvert diameter by the method best suited to the conditions. Check by another method. If a large diameter is called for, consider the use of a flared entrance to reduce the diameter. Check the outlet velocity. If it is too high, which would result in channel scour below the outlet, increase diameter until desired velocity is attained.

9. Consider whether any debris control structure is needed, and design.

10. Print the culvert station, type, diameter and length on the road profile. Note any special instructions regarding installation or debris control. (Section 728)

11. Study the profile to determine the location of any additional lateral drainage culverts. Refer to the Culvert Spacing Table, Article 650.3. Mark the location and size of such culverts on the profile.

12. Summarize the total lineal feet of each diameter of culvert.

728 DEBRIS CONTROL

728.1 NEED FOR DEBRIS CONTROL. Accumulation of debris at the culvert inlet reduces culvert efficiency and may result in damage to the fill. Floating debris, such as the smaller residue of logging slash, may dam the culvert entrance, reducing waterway area. It may also catch soil detritus which will plug the culvert. An abrupt break in gradient between channel bed and culvert, as on steep slopes, results in suddenly lowered water velocity and deposition of soil detritus.

Where upstream conditions are such that debris accumulation is likely to occur, the construction of a debris barrier is indicated. Among such conditions are: present or future logging slash in the channel above the culvert, steep flow gradient, sandy or silty stream beds, and erosible soils. The frequency of attention by the road maintenance crew during the season of peak discharge is another factor to be considered, in determining whether debris or detritus control structures are necessary.

728.2 DEBRIS CONTROL STRUCTURES. Some of the types of debris or detritus control structures recommended for forest roads are illustrated in Figure 728-1. The size of the components of a structure will depend upon the size and quantity of debris and the velocity of the water at flood stage.

1. In narrow, V-shaped valleys, the grizzly type of trash rack, Figure 728-1, is recommended. The vertical component of the weight of the debris, and of the water flowing over it at flood stage, helps to hold the rack in place.

2. In flat-bottomed, U-shaped valleys, with low stream gradient a triangular deflector, pointed upstream, will deflect floating debris to the banks. The deflector may be a crib of poles or chunks weighted with boulders. (Figure 728-2)

3. Where a steep hillside draw leads to a culvert on a lesser slope, the "bear trap" type of crib over the culvert inlet is recommended. (Figure 728-3)

DEBRIS CONTROL STRUCTURES

FIG. 728-1 GRIZZLY OR TRASH RACK

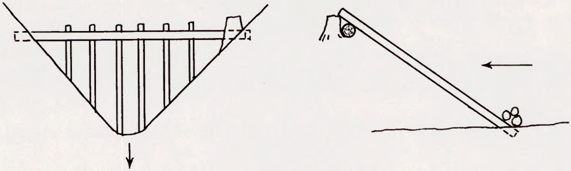


FIG. 728-2 CRIB DEFLECTOR

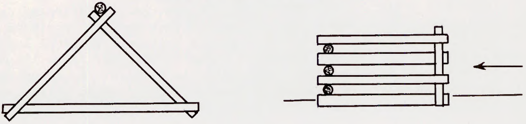
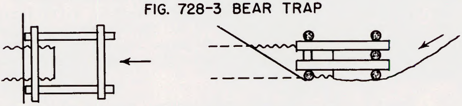


FIG. 728-3 BEAR TRAP



DETRITUS CONTROL

FIG. 728-4 PERFORATED RISER

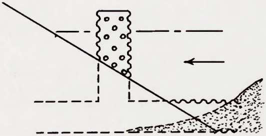
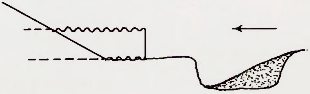


FIG. 728-5 CATCH BASIN



4. Clogging with soil detritus may be prevented by using a riser of perforated pipe, extending from the culvert inlet to above high water. (Figure 728-4) Digging a catch basin upstream will provide detritus deposition temporarily. (Figure 728-5)

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CONTENTS

800 CONSTRUCTION ENGINEERING

811 CONSTRUCTION ENGINEERING

Division 800 encompasses the work of the forest road engineer who exercises engineering supervision during the construction of a road as well as inspection for road contract compliance. The construction engineer is also referred to as the "resident engineer". The construction engineer is in reality the project construction manager. His responsibilities begin as soon as the contract for construction, either as an adjunct to a timber sale or as a separate road contract, is awarded and work starts. He controls the project by means of accurate and complete "staking" and thorough checking for compliance with engineering specifications and contract provisions. His success is to a considerable degree dependent upon the complete enlightenment of and understanding with the contractor* and his superintendent or foreman as to specifications, contract provisions and other matters relevant to the project.

A pre-construction conference, attended by the contractor, his superintendent or road foreman, and Bureau of Land Management officers involved should be held before the project work starts. It is important that the men who direct field operations of the contractor and the Bureau of Land Management attend. Such a meeting would produce far better results than a high level assembly from which information relative to contract interpretations and mutual understanding often trickles down through various administrative levels to the field men in an incomprehensible, incomplete and impractical form.

The requirements for knowledge and experience, for the use of judgment and for responsibility and authority of those functioning as construction engineers cannot be overemphasized.

Good location and design of a road can be ruined by shoddy execution resulting in a poor facility, costly to maintain and unduly expensive to haul over. Careful attention to the details of construction is, therefore, as important as location and design.

Proper control of a project recognizes the fact that although the plans and specifications are prepared by the government, defining the work to be performed once a contract is signed, the government has no more right to change contract requirements than the contractor has a right to change his unit prices or his obligations to the government in the case of a road built as a condition of a timber sale.

Technical details of the construction engineer's work are given in Chapter 830. Much of Division 600 SOIL ENGINEERING is also germane to construction engineering.

* The term road contractor as used in Division 800 may denote a timber sale purchaser who builds a road as an adjunct to a timber sale contract or a contractor who builds a road in compliance with a standard

government contract. In either case, the contractual obligations are similar.

812 CONSTRUCTION ENGINEERING STANDARDS

No hard and fast rules or formulae are given for the purpose of determining the intensity of construction engineering. Often, due to lack of qualified personnel, or simply personnel, compromises with the desirable have to be made.

Prior to the start of work on any road project, a conference of the individual who will have the direct construction engineering responsibility and his supervisors should be held. At this time the supervisors should be apprised of the total magnitude and import of the construction engineering involved in the project under consideration. If, as is frequently the case, the attainable does not match the desirable in the matter at hand, the practical alternates should be agreed upon. A written record of the agreements reached should be furnished the construction engineer. Thus, if a road project which, by virtue of perfection of location, survey and design and class of road merits continuous attention of a construction engineer, receives only a casual inspection at infrequent intervals, "goes sour," the real reason for failure will be factual and not a matter of conjecture or "buck passing."

If a road is important enough to be engineered in survey and design, it is equally important to give the construction the engineering supervision that will ensure the desired results. Construction engineering should be recognized as concomitant with reconnaissance, survey and design.

813 INSPECTION PRIORITIES

813.1 CONSTRUCTION ITEMS TO INSPECT. Following is a time table and check list of construction items to inspect. Technical details for each item are given in Chapter 830.

1. Before clearing and grubbing
   a. References and bench marks
   b. Clearing boundary line
   c. Pioneer road location
2. Before grading
   a. Clearing line
   b. Segments of right-of-way completely cleared and grubbed.
   c. Slope stakes and center line stakes, if required.
3. During grading

a. Culverts

b. Fill material

c. Compaction of fills

d. Proposed changes requiring authorization

e. Ditches

f. Subgrade width (especially added width on fills and curves)

g. Turnouts, spacing and width

h. Compliance with profile (designed roads)
Maximum gradient (other roads)

i. Compliance with plan (designed roads)
Maximum degree of curvature (other roads)

j. Bank slope ratios

k. Subgrade compacted and smoothed

4. During surfacing

a. Suitability of surfacing materials

b. Depth of surfacing

c. Width of surfacing

d. Proper processing of surfacing

e. Concomitant surfacing of turnouts

f. Surfacing started from rock source

820 EFFECTIVE CONTRACTOR RELATIONS

821 COMMUNICATIONS

821.1 IMPORTANCE OF COMMUNICATIONS. The construction engineer is primarily concerned with getting the road built to specifications. His effectiveness is dependent upon his communication with the contractor and the construction crew. He can accomplish more through education, cooperation and persuasion than he can by exercising authority. If the contractor or his crew has not been accustomed to building designed roads, or other roads to Bureau of Land Management specifications, the engineer's job is also one of education. It is important that they (the contractor and his crew) thoroughly understand all contract provisions and Bureau of Land Management road specifications and the reasons for them. The ensuing suggestions are given for the guidance of the engineer in communicating with the contractor and his construction crew. See Section 811 for instructions for preconstruction conference.

821.2 COMMUNICATION WITH CONSTRUCTION CREW. Be on hand when grading starts. Take along extra copies of the plan and profile and give them to the bulldozer operators as well as the construction foreman. Go over the specifications and plan and profile and explain them to the crew. Show them the stakes and references and tell them what the marks on them mean.

Take a copy of the contract relating to the road with you. Sometimes the contract specifications are kept in the company office and do not get down to the men in the field. Explain the reasons for the specifications.

Let them know that you are there to help them get the road built to specifications, and that you are not there just as an inspector. Set and mark accurately slope stakes from the reference points, "Swede levels" and culvert stakes. Help the construction foreman to plan the most economical movement of earth by compiling quantities by road segments and computing balance points and marking them on the profile.

821.3 COMMUNICATION BETWEEN BUREAU OFFICERS. It is essential to good relations with the contractor and his crew that lines of communication be maintained with the Bureau construction engineer concerned with the road project. It is preferable that the construction engineering and complete responsibility for the management of the construction contract be vested in one individual. The so-designated construction engineer, while accountable to and under the supervision of superiors, will be the sole individual giving orders or instructions to the contractor and his crew. In case of dispute, the construction engineer would consult with his superiors for resolution of the controversy.

Nothing is more disruptive during construction than conflicting instructions given to the contractor by various and sundry Bureau inspectors and officials.

Uniformity in construction engineering and road inspection procedures is also desirable for good contractor relations. Contractors may have, or have had, road projects in other units or districts. If marking methods or procedures vary, confusion may result. If one unit is more lenient than another, or authorization for changes in the road are handled differently, relations with the contractor will suffer. Communication between officers concerned to achieve uniformity will contribute to better understanding and compliance on the part of contractors.

822 CHANGES IN DESIGN DURING CONSTRUCTION

822.1 NEED FOR CHANGES IN DESIGN. No changes in design for the operator's convenience or profit are permissable. However, when clearing and grubbing of a segment of road right-of-way is completed, the desirability of making changes to improve alignment or profile may become evident. Features that were hidden from the road locator by timber or brush may be revealed. As grading progresses, alterations in plan or profile may become desirable for a number of reasons. Rock on steep side slopes may be closer to the surface or deeper than anticipated, indicating the raising or lowering of the grade line. A road designed for summer construction but built during wet weather may require changes to compensate for the larger earthwork shrinkage factor. The soils exposed by excavation may be unsuitable for fills. The plan and profile is a guide, subject to authorized change, especially if the road has been office-designed from a P-line, and the L-line was not staked. Recognizing that some changes in design during construction are inevitable, the following procedure for authorizing such changes is indicated.

822.2 AUTHORIZATION PROCEDURE. When the operator proposes deviations from the road design, he informs the construction engineer who arranges to make an inspection on the ground in company with the operator. The engineer's guiding principle in determining that the change is acceptable should be that it is: "as good as, or better than, the Bureau design." If he finds that it is acceptable, he writes a memorandum for the signature of the district manager, who is the only officer authorized to make changes in contract specifications. This letter becomes a part of the contract. On receipt of this letter, the authorized change may be put into effect. The operator should be informed of this procedure, and the length of time it requires so that the progress of construction will not be hindered.

830 TECHNICAL DETAILS OF CONSTRUCTION ENGINEERING

831 PRIOR TO CLEARING

831.1 CHECKING CLEARING BOUNDARY LINES. If a road is constructed under the provisions of a timber sale contract, and the clearing boundary line was established before the slope stake reference points were set, the construction engineer should check the boundary lines for sufficiency of clearing width. This should be done before the timber sale is made. If any revisions are needed, request the unit forester to have the boundary tags moved, and the additional timber cruised.

On the upper side watch for snags or other "danger" trees which could reach the road, and for large or leaning trees close to the top of the cut. The weight of the tree on the soil mass weakened by the cut is a frequent cause of slides. Undercut roots may result in a tree falling across the road. Check the clearing line position with respect to the slope stake points.

On the lower side, check whether the clearing line is far enough away from the center line so that debris can be pushed outside the road prism. On benched cross-sections, the clearing line should be established so that waste earth will not pile up around the boles of merchantable trees.

The importance of a wide clearing to "daylight" the road, for safety and to minimize road maintenance cost, should not be overlooked. Clearing well ahead of grading to dry the earth will improve grading performance.

831.2 CHECKING REFERENCES. Since survey points between clearing limits will be obliterated during the clearing and grubbing operation, it is essential that points which will have to be re-established are referenced. Before felling of right-of-way timber begins, inspect the referencing. Reference points may not have been set back far enough from the clearing boundary line, or at close enough intervals. Set additional reference points as needed. (Chapter 560)

Check the bench marks for sufficiency and protected situation. Bench marks are needed in the vicinity of high fills, through cuts, bridges and at intervals where gradient is at or near the allowable maximum.

831.3 PIONEER ROADS. Pioneer roads are often pushed through in a haphazard manner which makes subsequent grading to the designed cross-section difficult. On side slopes the best location for the pioneer road is usually along the top of the cut bank. However, on side hill fill sections, building the pioneer road along the toe of the fill slope will provide a bench for holding and compacting the fill. The yarding of the right-of-way timber also influences the location of the pioneer road. It is best to discuss the pioneer road location with the contractor in advance to ensure that all the problems involved have been considered, and the best solution determined.

832 PRIOR TO GRADING

832.1 INSPECTION OF CLEARED RIGHT-OF-WAY. Before grading begins, inspect the cleared right-of-way to see that all debris has been removed from the road prism. A given segment of the road should be completely grubbed before grading begins. Note particularly that no loose debris remains between the line of the top of the cut bank and the clearing line which would slide down into the ditch later. Also that no stumps, windfalls or other organic material are left to be covered by fill earth. Subsequent decay would cause fill settlement. Debris should be pushed to the lower side next to the clearing line. Right-of-way logs to be loaded out later should be piled where they will not interfere with grading to design. On relatively flat ground, stumps are sometimes left too close to the shoulder of the road. They interfere with grader maintenance operations.

Note whether debris has been deposited in streams. If so, require the operator to remove it. Check the clearing boundary line for illegal felling or avoidable damage to trees near the line.

832.2 RE-STAKING. If slope stake reference points were set, it is desirable to set upper slope stakes from them. This gives the bulldozer operator the exact point to start cutting and ensures grading to the correct bank slope ratio. Slope stakes are also needed at the toe of high fill slopes. If the road was not previously slope staked, re-stake the center line from survey line reference points and then set slope stakes.

The extent to which center line staking is done depends upon the standard of road. As a minimum, center line stakes should be set on sharp curves, switchbacks, fills and at the ends of tangents. If an error in stationing is found, or revision made, put in an equation. Do not change stationing ahead.

Where the road gradient is near the maximum for the standard, the use of "Swede levels" is recommended. A Swede level is a high stake or pole with a cross bar nailed to it at a height above the finished grade equal to the eye height of the bulldozer operator above the bottom of the tractor tracks. Swede levels are usually set on or below the lower shoulder line. When the operator has cut down to where the cross bars are in alignment vertically, he is on grade. When his line of sight is above the bars, he knows the depth yet to be cut.

The engineer should instruct members of the construction crew in setting construction stakes so they will know how to replace needed stakes during his absence. The construction foreman should be encouraged to get and use a hand level and a 50 ft. tape on a reel. A rod, hand-made from a piece of lumber, or a pole marked with kiel in feet and 0.5 feet, will suffice.

832.3 TAKE-OFF FROM EXISTING ROAD. The take-off of new construction from an existing road is difficult to design in the office, especially from a P-line survey. It should be direct located in the field. The take-off center line should be staked and leveled, and the profile plotted together with a segment of the existing road to ensure adequate grade separation. (Figure 423-2) The grade on the new road must coincide with the grade on the existing road until the center lines of the two roads are separated by the sum of the half-widths of the two road beds.

Take-offs for spurs from a main road should be constructed when the main road is graded. This will obviate many difficulties later on, especially on steep hillsides. The spur take-offs should be graded a short distance beyond grade separation point.

833 DURING GRADING OPERATION

833.1 STAKING CULVERTS. Before the culvert bed is prepared, stake both the inlet and outlet of the culvert. Set reference points far enough away so they will not be disturbed during bed preparation. After the bed is prepared, and before the culvert is laid, restake inlet and outlet from the reference points. Culvert design is covered in Chapter 720. In staking culverts bear the following in mind:

1. Alignment. Align the culvert with the natural stream channel unless this would result in an uneconomically long culvert, or a sharp bend in water flow near the in-toe of the fill. At steep gradient streams, consider the relative merits of skewing the culvert to discharge to one side of the fill, compared with aligning normal to the center line, discharging on the fill slope into a splash pan or on rock rip-rap. On erosible soils, the skewed culvert is preferred to allow sediment to filter out on the ground before the water returns to the channel. Otherwise, the alignment which will give the shorter culvert length and lesser total cost is the preferable one.

2. Elevation. Recommended practice is to place the bottom of the culvert as follows: inlet, at or slightly below the elevation of the stream bed; outlet, at or above the water surface elevation. Set hubs at inlet and outlet and mark the vertical distance from the hub to the bottom of the culvert on the guard stake.

3. Gradient. Culverts are normally laid on the natural gradient of the stream bed. If the culvert has been designed for a specific gradient, stake accordingly. The preferable range of gradients is between 2 and 6 percent. Less than 2 percent gradient may result in deposition of sediment in the culvert. Steep gradients cause scouring at the outlet, and undue wear in the culvert. Avoid breaks in culvert gradient. If unavoidable, the steeper gradient must be at the outlet segment. Culverts on weak foundation soils under high fills should be cambered so the culvert will not sag under fill settlement. The amount of camber is a matter of experienced judgment.

833.2 CULVERT PLACEMENT. It is of the greatest importance that correct practices be followed in the installation of culverts. The beds of all culverts should be inspected before culverts are laid. The engineer should be present when the larger culverts, say over 36 inches diameter, are laid. It is especially important that he be present when culverts requiring strutting are laid. Following is a brief summary of recommended practices for laying corrugated metal pipe culverts. For further details refer to Chapter 52 of the Armco Handbook (1/).

1. Bedding. The bedding should provide stable uniform support for the culvert throughout its supported length. The bed should be of firm well-compacted granular soil. No rocks or boulders are permissable. The bed should be rounded on the culvert radius to a depth of one-sixth the diameter. Rocky or soft, unstable soil should be excavated to a depth of not less than 6 inches, and a width of two diameters, and backfilled with sand or fine gravel.

2. Strutting. Culverts larger than 48 inches diameter should be strutted. The use of shop-strutted pipe is recommended. Considering the labor time involved in field strutting with timbers, shop-strutted pipe is generally competitive in installed cost. The correct method of field strutting is shown on page 444 of the Armco Handbook (1/). The minimum size of timbers recommended for struts and sills is 4 x 4 inches. For fills of moderate height, the use of pipe deformed in the factory to 5 percent elliptical is an acceptable alternative to strutting, and would result in a considerable saving. Care must be taken in laying the elliptical pipe to get the longer axis vertical.

3. Laying culvert pipe. Care must be taken in handling galvanized, corrugated metal pipe to prevent denting or scraping the galvanizing coat. Pipe should be rolled or hoisted, not dragged over the ground. It should not be dropped from a truck. If pushed with a bulldozer, the pipe should be protected from the blade with a plank, and from scraping along the ground with skids or poles. The manufacturers' instructions

should be strictly followed.

4. Backfilling and tamping. Backfill of good granular soil, preferably sand or fine gravel, should be placed by hand and well tamped under the haunches of the pipe, and then filled and tamped up to the top of the culvert to avoid damage from machine during the subsequent filling operation. Fill soil should then be placed evenly in layers from both sides by bulldozer until the culvert is covered to a depth of at least 1 ft. over pipes up to 36 inches in diameter, and 1/3 the diameter over pipes 36 inches and larger. Care must be taken not to push the culvert out of alignment. The bulldozer should not be permitted to cross over above the culvert pipe until the soil supporting the sides has been compacted and the pipe is protected by a cover of not less than 1 ft. for all pipe 12 inches to 36 inches in diameter or 1/3 the diameter over pipes 36 inches and larger. If this brings the fill surface above subgrade elevation, it can be cut down to grade before surfacing.

833.3 CONTROL OF MATERIALS. The construction engineer should be thoroughly conversant with Division 600, SOIL ENGINEERING. As excavation proceeds, he should note the soils exposed and their suitability as subgrade materials. Pay particular attention to fill soils and their compaction. Investigate fill foundations well ahead of earth-moving, and insist on the removal of debris and any weak surface soil layer. Also require scarification of steep sidehill valleys to get a bond between fill and foundation. If topographic conditions permit, require the fills to be built up in horizontal layers, not in vertical layers as bulldozer operators are inclined to do. See Chapter 640, Subgrade Compaction. Check that no chunks or slash are deposited in the fill.

Examine deposits of possible surfacing rock revealed during grading. If there is any doubt as to the suitability of rock proposed to be used for surfacing, have it tested well in advance of the surfacing operation. (Articles 633.2 and 633.3)

834 PRIOR TO SURFACING OPERATION

834.1 CHECKING SUBGRADE. During grading operations, check the following listed items. These items must conform to specifications before the grading portion of the contract is accepted as complete and surface operations begin. Keep complete field notes on all items found to be deficient. Set flagged stakes at points which need correction. Mark the correction required on the stake. Check all the following items at critical points at one time:

1. Bank slopes. Check bank slope ratios with Abney level. If slopes appear deficient, check top of cut and toe of fill slope from slope stake reference points. Note whether any overhanging debris is present which would slide down into the ditch.

2. Subgrade width. Check road bed width with tape, especially for widening on curves and fills. At full bench sections, disregard fill section which will slough off in first winter after construction.

3. Compliance with profile (designed roads) or maximum gradient specification (other roads). Check gradient with Abney level.

4. Compliance with plan (designed roads) or maximum degree of curvature (other roads). One way of measuring degree of a circular curve is to lay off a 62 ft. chord. Measure the middle ordinate in inches at the 31 ft. mark. This equals the degree of curve. Convenient equipment is a 100 ft. tape on a reel for measuring the chord and a flexible carpenter's rule for measuring middle ordinate in inches. A 62 ft. length of heavy cord with various subgrade width points and mid-point marked with a piece of flagging tape is a useful tool for rapid checking of width and degree of curve. An alternate approximate method making use of hand compass and pacing can be done fairly accurately by one man. The method is as follows:

a. The deflection angle of a 50 foot chord is one-fourth and for a 25 foot chord it is one-eighth the degree of curvature. Use 50 foot chords on larger curves and 25 foot chords on smaller curves.

b. Get in the middle of the curve and line out an approximate tangent to the curve.

c. Pace or tape a 25 or 50 foot chord, depending on the curve.

d. Measure the deflection angle from the tangent to the chord.

e. Multiply deflection angle by 8 or 4 for 25 or 50 foot chords respectively to get degree of curve.

5. Subgrade compaction and finish. The subgrade should be smoothed with the grader before surfacing just as though the subgrade were to be the finished road. If the operator has a grader which can raise the blade to the side, the back slope should also be smoothed to reduce ravel. Test the compaction with a "Pocket Penetrometer," if available. (Article 622.2)

6. Ditches. Check depth and width. A convenient ditch templet may be made with a light cross bar projecting 3 feet on one side and 1 foot or 3/4 foot on the other side (depending upon the cut bank slope ratio) fastened to a staff 1 foot from one end of the staff. Set this end of the staff in the bottom of the ditch. If the ditch is correctly made, the longer segment of the cross bar will touch the shoulder of the roadway and the shorter bar will touch the bank. The ditch should be widened at the inlet to lateral drainage culverts.

834.2 CHECKING TURNOUTS. Turnouts are vital to the safety of everyone who will travel over the road. While turnouts should be designed and staked as an integral part of a road, they are often found to be deficient, both in number and in dimensions. Experience has shown that turnouts need continuous attention from the construction engineer. When exact location of turnouts is not specified, check the intervisibility, and maximum spacing, on the ground. If more turnouts are needed, require them to be built before the surfacing operation begins. When the turnouts are specified on the plan and profile, the locating engineer may not have visualized all the turnouts needed. In this case, the construction engineer should require the operator to build the additional turnouts.

835 DURING SURFACING OPERATION

835.1 OBTAINING REQUIRED THICKNESS. Where surfacing material is scarce or expensive, the operator may be inclined to skimp on the thickness of surfacing rock. The construction engineer can guard against this by using the tables in Article 632.5 showing the distance in lineal feet a dump truck load of a given capacity will spread for a required thickness. Setting short stakes on the shoulders, with the tops of the stakes at surface elevation, will help to obtain the correct surfacing thickness. Such stakes are set with hand level and rod.

Surfacing width and crown should also be checked for compliance with specifications. See Article 632.4 for surfacing compaction instructions. Surfacing should start at the rock source, so that the dump trucks will always be traveling on surfacing and not on the subgrade. The grader should not blade more than 25 to 50 cu. yds. per station at a time.

835.2 SURFACING TURNOUTS. It is the practice of some operators to defer the surfacing of the turnouts until after the roadway is surfaced. This practice results in uncompacted turnout surfacing, in lack of bond between turnouts and roadway surfaces, and often in insufficient length and width of surfaced turnout. Turnouts should be staked for surfacing and surfaced concomitant with the adjacent roadway. Set stakes where the turnout approaches leave the roadway and at the beginning and end of the full width of the turnout.

836 THROUGHOUT CONSTRUCTION

836.1 PRODUCTION AND COST DATA. The construction engineer who is frequently present during road construction has an opportunity to collect accurate production data from which cost data can be compiled. Such data can be of great value in estimating future road construction costs. During the progress of construction, keep a detailed record of the equipment and the number of men working and the amount of work done during the periods of time between inspections. Note the variable conditions of forest cover, topography, soil, weather, etc. involved. Analysis of the data will give valuable general cost information for appraisal.

Cost information acquired in this manner should not be considered in the same category as formal cost studies, usually conducted under state office direction. Formal cost studies require an exactitude of procedures, controls and measurements that usually are not practical within the usual workaday activities of the forest engineer.

837 PHOTOGRAPHS

In the event of dispute or contention with a recalcitrant contractor, photographs of the controversial construction practices should be taken. Good photographs can be of great value in supporting documentary evidence in establishing facts, and facts are important in settling contract violations.

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